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POLYMER FILM OVERLAY SYSTEM FOR MERCURY CONTAMINATED SLUDGE - PHASE I

Michael U. Widman, et al

Battelle Columbus Laboratories

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POLYMER FILM OVERLAY SYSTEM FOR MERCURY CONTAMINATED SLUDGE PHASE I

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POLYMER FILM OVERLAY SYSTEM FOR MERCURY CONTAMINATED SLUDGE - PHASE I

by

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for the

Office of Research and Monitoring

ENVIRONMENTAL PROTECTION AGENCY

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POLYMER FILM OVERLAY SYSTEM FOR MERCURY CONTAMINATED SLUDGE-PHASE I,

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Battelle Columbus Laboratories, Ohio

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~~Research was conducted to study~~ various polymer films to be used in sealing mercury contaminated sediments. Materials were selected for detailed study on the basis of barrier properties to mercury compounds, strength, handleability, and estimated service life. Although most polymers are effective barriers to $HgCl_2$, the resistance to organic compounds can vary from poor to very good. Nylon 6 and high density polyethylene proved to be the most effective barriers to organic mercury. It was concluded that polymer films can be effectively utilized to seal mercury contaminated sediments. Estimated costs for film deployment are given and equipment concepts for film deployment were demonstrated. The nylon 6 system was recommended for field demonstration. (Smith-Texas)

*Mercury, *Pollution abatement, *Water pollution, *Public health, *Toxicity, Water pollution sources, Chemicals, Plastics, Polymers, Sediments, Cost analysis, Economics

*Lake sediments, *Mercury compounds, *Nylon 6, *Polyethylene, *Mercury barriers, *Mercury pollution, Application equipment, Hot melts, Latices, Hydrocarbon polymers, Dimethyl mercury, Mercuric chloride

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Richard M. Smith, Jr. | Texas Univ, Austin

ABSTRACT

Concepts for dispensing of polymer films underwater and over mercury contaminated sludges were generated. The candidate systems examined were based on coagulable materials, hot melt polymer compounds, and preformed films. A large number of laboratory blends of the candidate materials in the first two categories were made and qualitatively evaluated to identity promising formulations. Experimental equipment appropriate to each concept was designed and experiments were conducted in an 18-foot-long test tank to establish the feasibility of the material-equipment systems.

The results of these experiments suggested that commercially available preformed films could be successfully dispensed from a roll and applied as an overlay on the mercury contaminated sludge.

Dialysis experiments were conducted to determine the permeability of the candidate materials to organic and inorganic mercury compounds. Preformed nylon and high-density polyethelene performed best in all categories. Microbiological and biological experiments showed that the preformed films and hot melt polymers were most promising.

A cost analysis showed that a preformed film overlay can probably be deployed for 1.5 cents to 3.3 cents per square foot, hot melt films for about 2.5 cents per square foot, and a coagulable nylon film for about 4 cents per square foot.

Based on this work the preformed film system was recommended for Phase II implementation.

This report was submitted in fullfillment of Project No. 16080 HTZ, Contract No. 68-01-0088 under the sponsorship of the Environmental Protection Agency.

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SECTION I

CONCLUSIONS

The experimental program described in this report demonstrates the technical feasibility of using polymer film barriers to isolate mercury-contaminated sediments. Three basically different polymer-equipment systems have been shown to be feasible for this application. The materials are effective barriers to mercury-contaminated sediments and specially prepared mercury solutions, have good strength, and will provide long service life. Practical equipment concepts for each system have been developed.

On a performance-only basis, the most effective polymer film material appears to be preformed nylon 6 (polycaprolactam). This film is an effective barrier to both inorganic forms of mercury (mercuric chloride) and organic mercury (methylmercuric chloride and dimethyl mercury). All of the other polymer films of special interest [high-density polyethylene, low-density polyethylene, polyvinyl chloride, alcohol-soluble nylon, and poly (ethylene-vinyl acetate) copolymer hot melts] have been shown to be equally effective as barriers to mercuric chloride as the nylon 6. However, none are as impermeable to the organic mercury compounds as the nylon 6, and they vary considerably in their capability of retaining these particular mercury compounds. The most effective of these other candidate materials is the high-density polyethylene. It is not known at this time how specific film properties such as crystal structure and molecular orientation will affect these results, but it is suspected that a biaxially oriented structure would improve the barrier performance to still higher levels of effectiveness.

The preformed nylon 6 film has been recommended for further evaluation in a field demonstration. This recommendation was based on performance considerations only; the cost of this system, however, is about 2 to 2-1/2 times greater than the next most effective system, the high-density polyethylene. On a total cost effectiveness, the latter may be preferable to the nylon 6 since its effectiveness as a barrier is still many times better than the remaining materials. In general, preformed films have also proven to be the most attractive alternative from an equipment concept. It is believed that developing and building equipment of this type for eventual implementation of the barrier concept can be accomplished for less cost and more quickly than for the other approaches.

The only material in this grouping that poses any environmental hazard in itself, and this is believed to be very slight, is the alcohol-soluble nylon. Deployment of this system would entail introducing small amounts of ethyl alcohol to the lake system. The quantities involved are not so large as to pose any real threat, but the laboratory studies

do indicate an increase in BOD (Biological-Oxygen-Demand). This system has one other undesirable feature - high cost. However, as with the preformed films, a workable equipment concept for this material appears to be fairly simple.

Hot melt films formed by casting on a rotating drum offer the greatest opportunity for varying the physical-mechanical properties of the barrier. The materials are inexpensive and practical to use and the equipment concept is quite feasible. However, this system is relatively complex compared to preformed films and its barrier properties are poorer. It is therefore less desirable from these points of view.

Sodium alginate films, originally developed for underwater salvage use, have been shown to be impractical for the present application. As suspected, they are highly biodegradable, according to our laboratory results. It is also believed that they would not provide effective barrier properties because of their high water content.

All of the polymer films have certain common problems. All require regularly spaced vent-holes to permit the escape of gases formed in the sediments, and all require some form of anchoring, even though the specific gravity may exceed that of water.

In summary, it is concluded that the polymer film barrier concept has considerable promise as a procedure for decontaminating water systems with mercury-rich sediments.

SECTION II

RECOMMENDATIONS

Promising candidate material systems and delivery techniques have been identified in this Phase I study for overlay of mercury contaminated sediments. One approach, that of using preformed commercial film, is recommended for future implementation because it appears to be the most easily implemented effective barrier with a minimum of development and capital equipment cost. Our experiments show that commercial films are available which can provide a wide range of cost and effectiveness.

Based on these results it is recommended that a Phase II field demonstration program be conducted. In the Phase II program, the following general tasks must be accomplished.

- Select and assess a suitable test site.
- Design a test program which will permit evaluation of the results of overlay of mercury contaminated sediments.
- Optimize a preform polymer material.
- Design and construct application equipment.
- Place and execute a polymer overlay in the test site.
- Evaluate the results of the experimental program and assess their implications for further action to overlay other mercury contaminated sites.

A plan for Phase II research program has been prepared and submitted to the Environmental Protection Agency. A summary of the approach described in that proposal is contained at the end of this report.

SECTION III

INTRODUCTION

Towards the end of the 1960's and into early 1970, commercially caught ocean fish species, as well as inland freshwater species, were found to contain excessive amounts of mercury. As a result, many lakes were closed to commercial fishing, and catches of selected species of salt-water fish were restricted. This led to a fairly comprehensive search by Federal and State authorities to determine the source of this mercury. The sediments of many major inland lakes and streams were found to contain large amounts of mercury, the result of years of dumping by industrial and other users of mercury. Government and industry action since that time has resulted in considerable progress in reducing the inflow of additional mercury contaminates, although the inflow has not been completely abated.

The large quantities of mercury in lake and stream sediments remain a major environmental problem. To deal with this hazard, the Water Quality Office of the Environmental Protection Agency solicited research programs to conduct research and to develop new and effective methods and technology for the control of pollution from these sediments. The study described in this report is a part of that program.

The objective of the Battelle-Columbus Phase I program was to determine the merits of isolating mercury contaminated sediments with barriers constructed of a polymer film and to indicate the most promising method to accomplish this end. Two interrelated goals had to be satisfied:

(1) Identify polymer film material systems capable of providing mercury compound barrier properties, and

(2) Develop equipment design concepts for dispensing the polymer films over the contaminated sediments and experimentally verify the feasibility of the material-equipment system in the laboratory.

The program was accomplished by screening candidate materials in three general categories. Coagulable materials, hot melt materials, and pre-formed materials. Equipment concepts for these classifications were generated and the material-equipment system feasibility verified by laboratory experiment and analysis.

This report contains recommendations, a general description of alternative systems, the experimental work and evaluation, and a discussion of a plan for implementation of the recommended approach.

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SECTION IV

DESCRIPTION OF CANDIDATE SYSTEMS

The research in this Phase I program has resulted in the identification of three promising material-equipment systems for overlay of mercury contaminants. These range from a relatively simple system which uses preformed film to the more complex concept which requires subsurface machinery to continuously cast hot melt films. Although all of the concepts have merit and appear to have the potential for successful overlay of mercury contaminated sludge, the approach using preformed film appears most advantageous. In the following paragraphs the basic principles of the material systems concepts will be described followed by descriptions and illustrations of the surface and subsurface equipment needed to implement these concepts.

BASIC PRINCIPLES OF THE MATERIAL SYSTEM CONCEPT

The basic principles of the concepts are quite simple; implementation of the concepts in the underwater environment however is considerably more complex.

Coagulable Polymers

An alcohol soluble nylon system was investigated during this program which appears to have almost ideal characteristics. The material is essentially a one-part system in which the alcohol in the alcohol-nylon solution is displaced by water when the polymer is extruded into the water. The nylon is insoluble in water and forms a tough continuous membrane.

Application equipment will consist of a means for pumping the predissolved alcohol-nylon solution to the subsurface apparatus. The subsurface apparatus must extrude a continuous and uniform film thickness of about 0.012 inch.

The most advantageous feature of this material-equipment approach is the simplicity of the system. The most serious drawback is the probable high cost of materials.

Hot Melt Materials

A hot melt material-equipment system provides the greatest opportunity

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for optimization of film characteristics, especially additives such as scavenging agents and other fillers.

Although a number of equipment approaches were tried in the laboratory, a continuous casting process or drawing down onto a rotating chilling surface produced superior results. Hot melt material is delivered to the subsurface apparatus from the surface through insulated and heated delivery lines. The subsurface dispensing equipment must be enclosed in a "pressure" hull and be equipped with seals to prevent the entry of water into the system.

The most advantageous characteristic of the hot melt material-equipment system is the wide range of film properties that can be formulated into the material and the high physical quality of the in situ formed film. A serious disadvantage is that the dispensing equipment and support equipment will be expensive to develop, construct, and maintain.

Preformed Film System

The development of an approach for the deployment of preformed films was an unexpected benefit of the Phase I research. It had been decided some time ago that this approach could not be satisfactorily implemented when in fact the in situ film-forming methods under investigation produce the same handling and deployment problems inherent in the preformed film approach.

The concept involving the use of preformed film received the benefit of the largest scale experiment in the program simply because it was easy and inexpensive to implement. With this concept, preformed film of commercial manufacture is unrolled from a subsurface roll of the material. A wide variety of preformed materials can be used including such inexpensive films as low-density polyethylene or more effective barriers such as nylon.

As a result of experiments with preformed films, concepts for physical stabilization of the dispensed film were generated. It is expected that one or more of these concepts must be applied to any of the candidate overlay systems for them to be successfully stabilized on the bottom.

The most advantageous features of the preformed film approach is the relatively simple equipment requirements, effectiveness of available materials, and short equipment development time required. The apparent disadvantage is the relatively large bulk of material which must be handled at the bottom.

Surface Support System

The overall approach contemplated for each of the candidate systems is quite similar. Basically a film of up to 20 feet in width is to be

deployed on the bottom at moderate depths. Although obstructions are anticipated, the concept is planned for relatively flat or rolling terrain. Figure 1 is an artist conception of the overall arrangement of the overlay deployment system.

The subsurface equipment is mounted on the end of an arm which extends to the bottom. A convenient method of providing this support would be to use a commercially available hydraulic crane or backhoe excavator which can be positioned on the deck of a barge. Figure 2 shows an arrangement of equipment or a barge which could be used for deployment of preformed film. A hydraulic crane or backhoe is modified to provide adequate reach and to accept the subsurface equipment. Rolls of film are also stored on the deck of the barge. The subsurface equipment is designed so that it can be loaded at the last station of the storage rack and the backhoe can swing film roll and dispenser over the end of the barge and into the water.

Figure 3 shows how the more complex systems like the hot melt film approach can be accommodated by a barge-mounted equipment arrangement. In this illustration, the hot melt apparatus is connected to the pumps and melting tank with an insulated and heated flexible pipe which is supported in part by the crane boom. Fuel tanks, heating plant, and basic hot melt material is also stored on the deck of the barge.

Subsurface Equipment System

The subsurface equipment concepts are quite similar for the preformed film and the hot melt material-equipment approaches. Basically the film is either formed on the hot melt system casting drum or unrolled from a large roll of preformed film before it is applied to the bottom. After the film has left the casting drum or dispensing roll, it goes over a dancer roll which controls film tension and is applied to the bottom under a foot roll. The foot roll is visualized as a large low pressure tire or roller which can easily negotiate bottom contours and discontinuities. The foot roll places the film in intimate contact with the bottom and this action squeezes the water out from under the film. Although this action tends to hole the film on the bottom, experiments have shown that anchoring is required to maintain physical stability of the film on the bottom. Several approaches to this problem have been conceived.

Figure 4 shows how this concept would look on the bottom. In this case a 20 foot wide roll of preformed film is being dispensed. The film has preapplied anchor weights attached to it which have been applied at a shore-based facility when the film was put onto the dispensing rolls. For a 20 foot width of film a foot roll of about 6 feet in diameter should be adequate to negotiate most bottom obstructions. "In situ" anchoring schemes are necessary for hot melt formed films and the alcohol solulable nylon films since the anchor weights cannot be applied before they are dispensed.

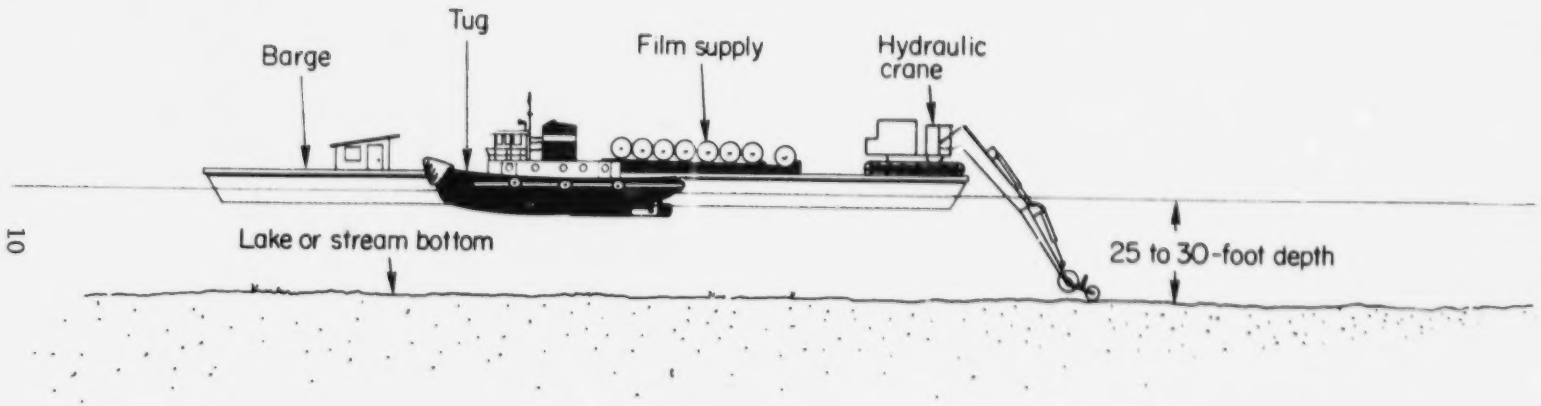


FIGURE 1. OVERALL EQUIPMENT ARRANGEMENT

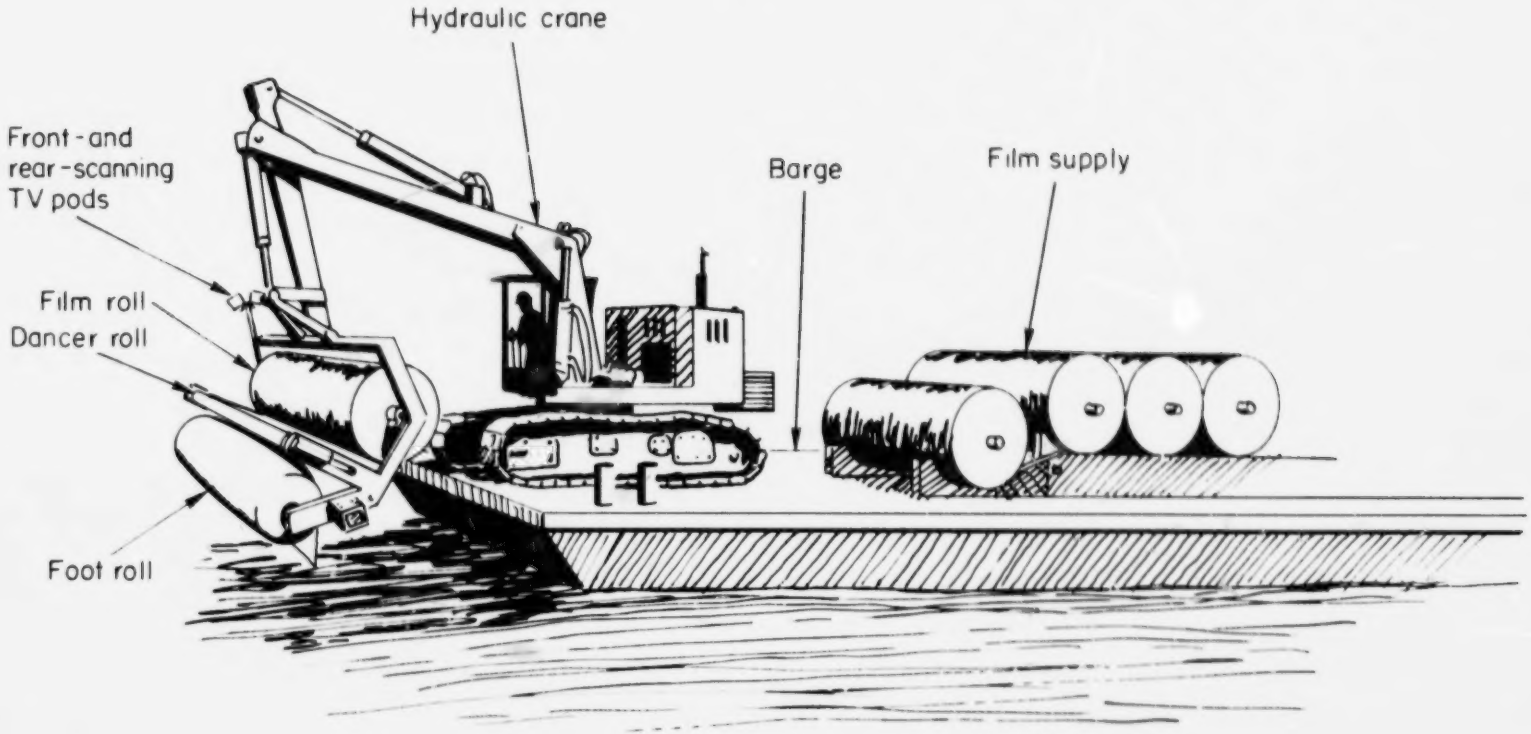


FIGURE 2. DECK ARRANGEMENT FOR BARGE-MOUNTED APPARATUS FOR PREFORM FILM OVERLAY SYSTEM

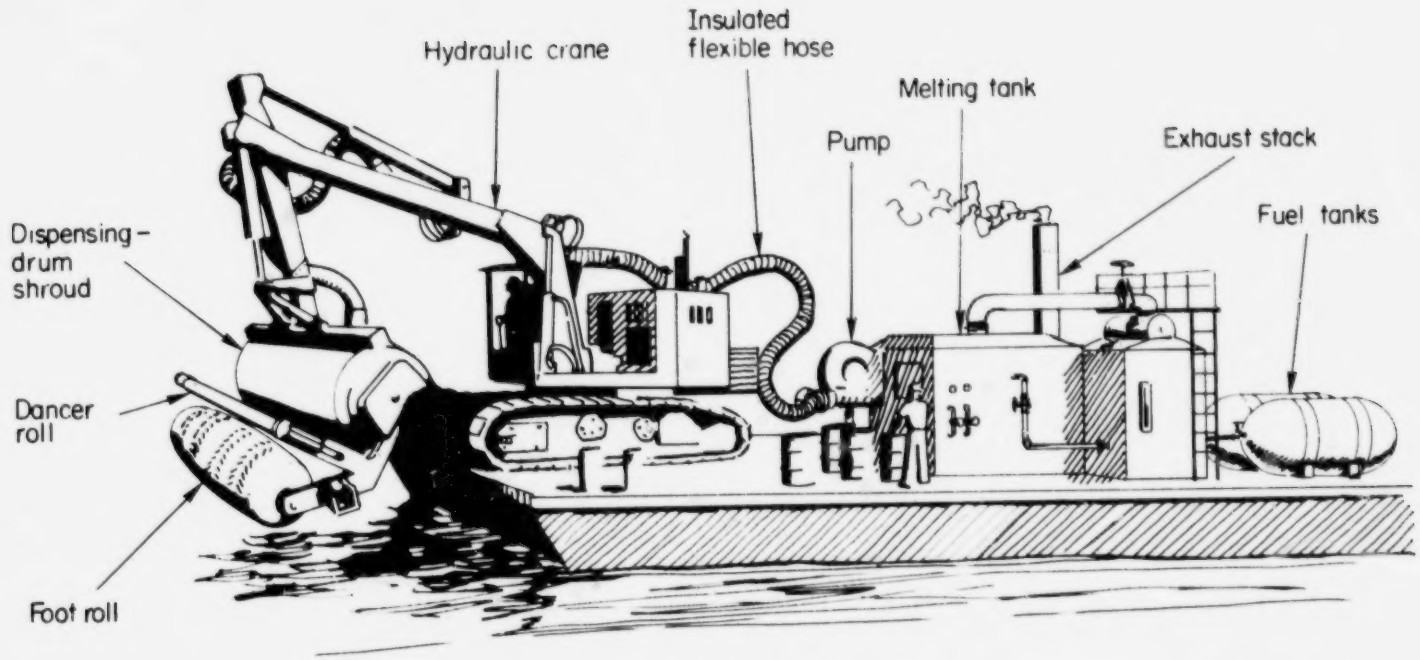


FIGURE 3. DECK ARRANGEMENT FOR BARGE-MOUNTED APPARATUS FOR HOT-MELT FILM OVERLAY SYSTEM

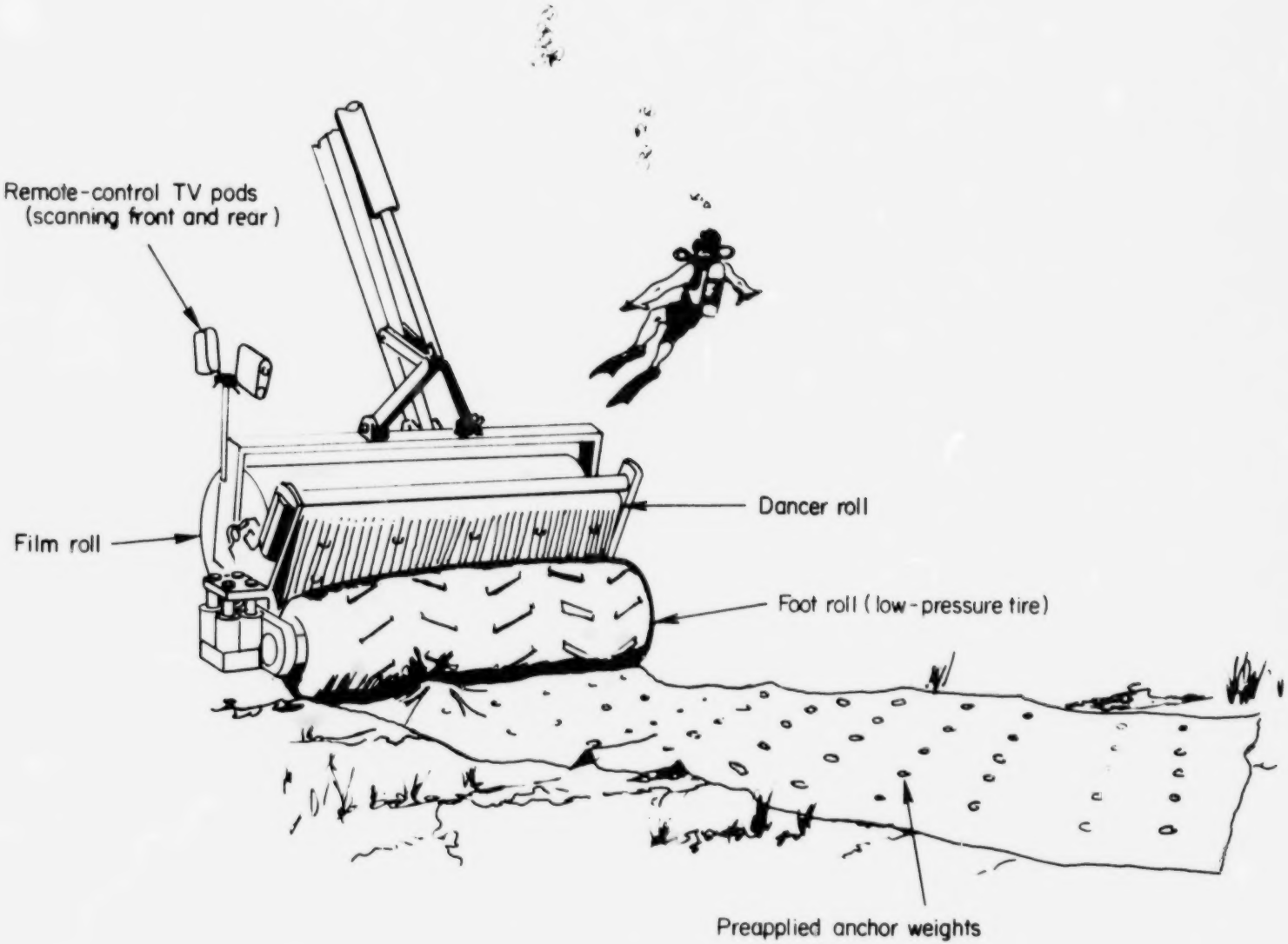


FIGURE 4. DEPLOYMENT OF PREFORMED FILM WITH PREAPPLIED ANCHOR WEIGHTS

Figure 5 shows the first of these anchoring systems being used with the hot melt dispensing apparatus. This anchoring concept uses helical formed wires that puncture the film. The helical formed wires are produced continuously from wire feed from the surface. In some bottom conditions they may actually provide a physical attachment of the film to the bottom in addition to the anchoring function provided by their weight. Note that independent suspension of the wire forming heads will be necessary to accommodate bottom contours.

Figure 6 shows a gravel ballast system being used with the preformed film dispensing unit. This approach can also be used with hot melt and alcohol soluble nylon material-equipment systems. With this anchoring apparatus, circumferential projections on the foot roll fold grooves or longitudinal pockets into the film as it passes under the foot roll. Ballast, either sand, gravel or other suitable material, is placed into these grooves to anchor the film to the bottom. Depending upon the softness of the bottom and on the availability of ballast material, this approach can provide a high degree of anchoring at a relatively low cost.

The alcohol soluble nylon film system probably would be anchored with the gravel ballast system. It is doubtful that the film would have become hard enough so soon after formation to be anchored with helical wires. Figure 7 shows the configuration of the subsurface apparatus for dispensing the alcohol soluble nylon films. The gravel ballast systems have been omitted for clarity. Note that a foot roll is not used for this concept. The foot roll would probably adhere to or break the film because some finite time is required for the alcohol to be displaced by the water and for a firm, tough film to develop.

RECOMMENDED APPROACH

Although all of the concepts for material and equipment systems appear to have the potential of satisfying the overall objective of providing an effective polymer overlay for mercury contaminated sludge, the approach which uses preformed films appears to be most advantageous. An analysis of the system shows a remarkable flexibility which will be very useful in implementation of the concept and in optimization of the treatment for specific contaminated sediments. The analysis of implementation costs in later sections of this report shows that the preform approach can be used to apply various polymer films at a range in cost of about 1.5 cents to 3.3 cents per square foot. These films have a wide range of barrier performance with respect to both organic and inorganic mercury compounds.

Because a prefabricated anchoring system can be used with a preformed film overlay, development of subsurface anchoring and ballasting equipment can be deferred until after the effectiveness of the overlay approach is verified in full scale field tests. Thus although the cost of the overlay

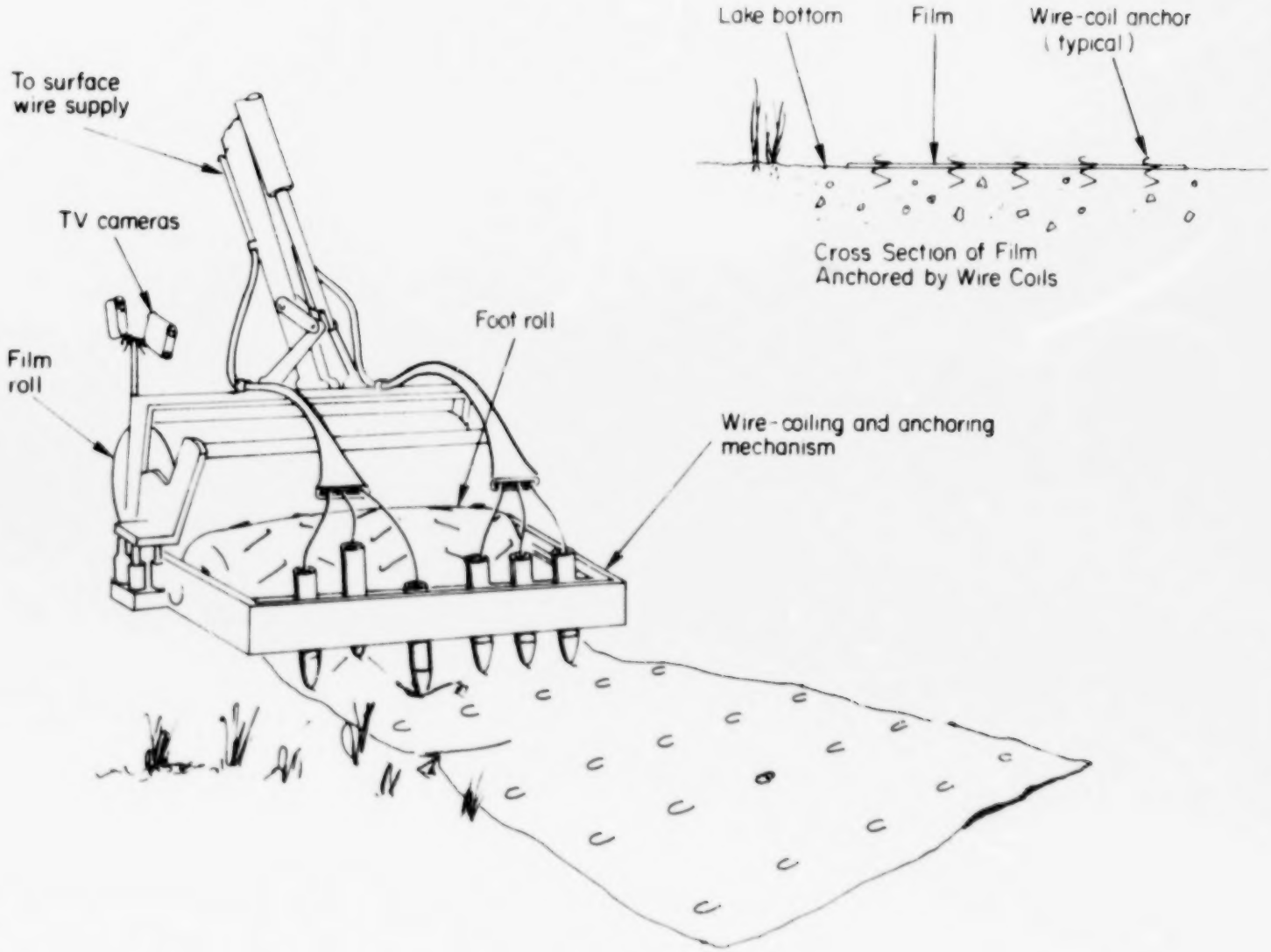


FIGURE 5. DEPLOYMENT OF PREFORMED FILM WITH WIRE-COIL ANCHOR SYSTEM

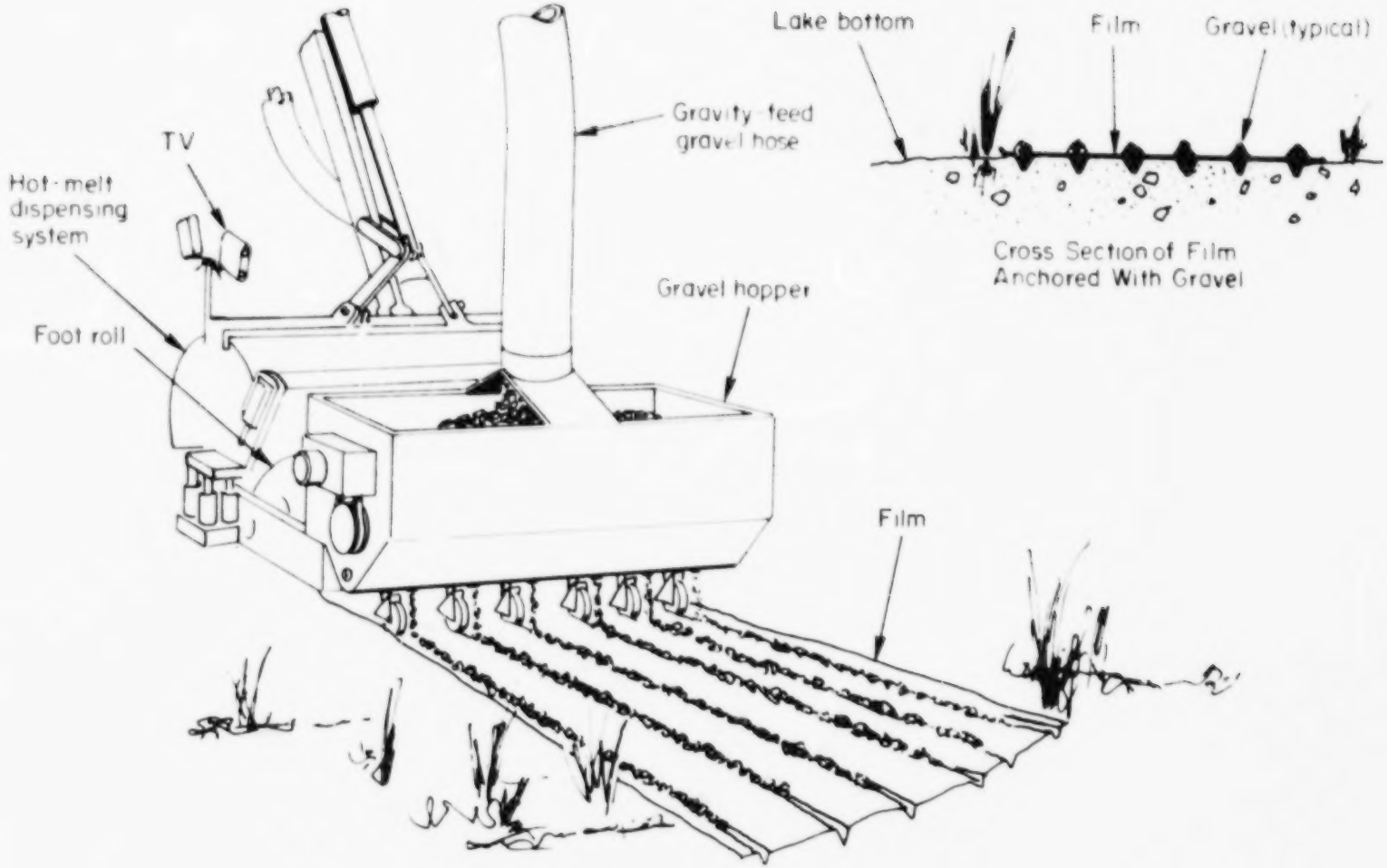


FIGURE 6. DEPLOYMENT OF HOT-MELT FILM WITH GRAVEL BALLAST ANCHOR SYSTEM

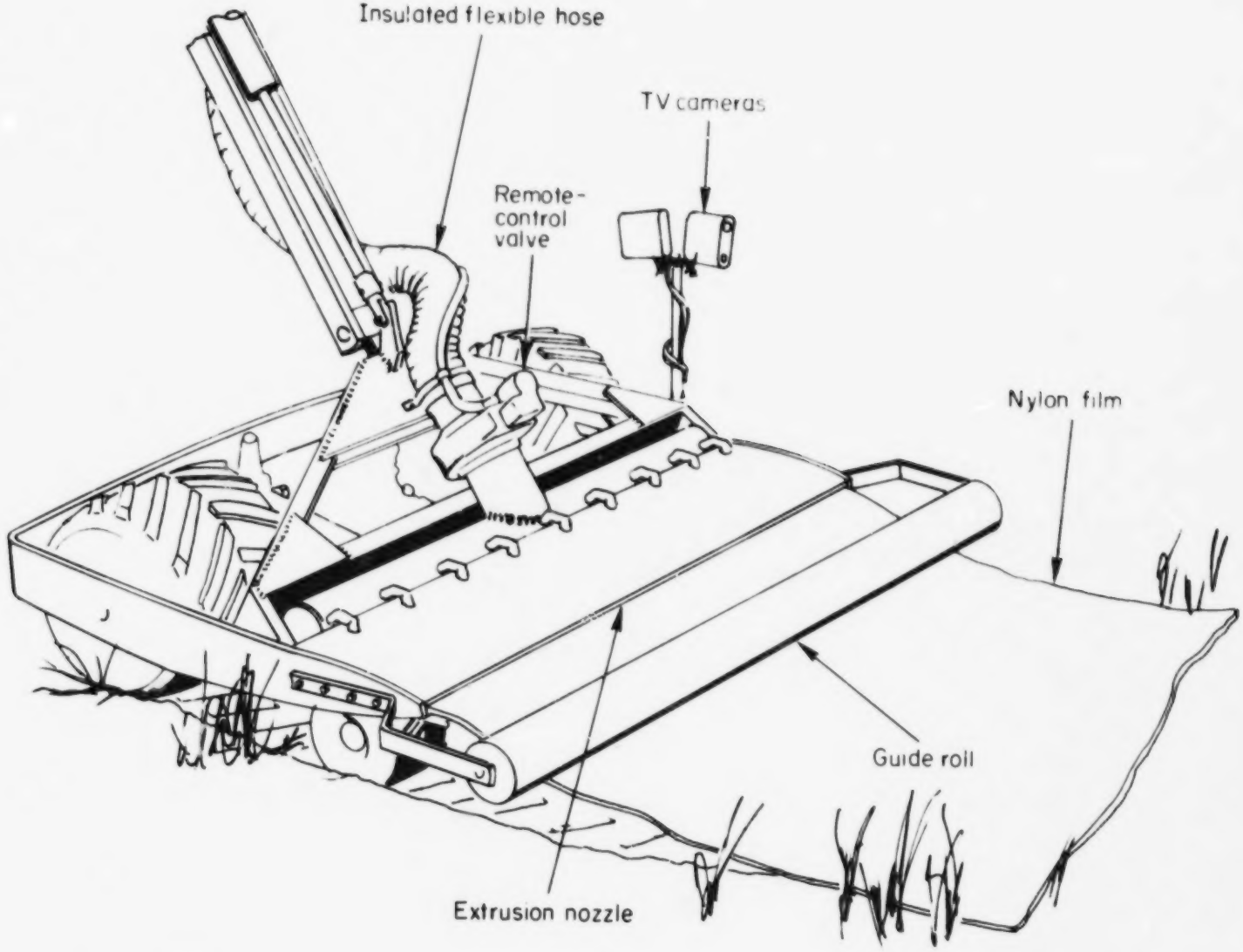


FIGURE 7. DEPLOYMENT OF ALCOHOL-SOLUBLE NYLON FILM

material will be somewhat higher, the development costs associated with the "in situ" anchor or ballast equipment can be omitted. Additional savings in development costs appear feasible because of the straight forward design involved in the subsurface film dispensing apparatus.

SECTION V

DISCUSSION OF EXPERIMENTAL PHASE

The experimental phase consisted of extensive material system development in the laboratory, design, construction, and implementation of large scale equipment tests. Material experiments, evaluation of barrier and of microbiological and biological properties of these materials and analysis of the cost inherent in the candidate systems were also accomplished in this phase.

MATERIALS

In a previous development program sponsored at Battelle by the U.S. Navy Supervisor of Diving, Naval Ships Systems Command (see references 1 and 2 in Section VII), the feasibility of silt stabilization was demonstrated by in situ formation of a gelled polymer film consisting primarily of alginic acid. This development was the initial basis for the concept of a polymeric film barrier for mercury-containing sludge deposits. The objective of the present program, however, differed fundamentally from the earlier development in the requirement to retain water-soluble species. This objective demanded films of much higher polymer density than was possible with the gelled alginates in order to maximize retention of the mercury compounds. All departures from the original gelled-polymer system resulted from these considerations.

The material formulations which were developed in the experimental phase of the program were latex systems, solvent systems and hot melt blends.

Latex Systems

Two inherent characteristics of latices make such systems particularly attractive for the in situ formation of barrier films: (1) low viscosity at relatively high polymer contents (generally between 50 and 65 percent for the unmodified latex), and (2) aqueous dispersions, thus eliminating any potential problems relating to the environmental impact of solvents, as well as eliminating the need of putting the polymer into solution which saves an operation that is generally necessary with organic solvent systems. Moreover, a wide choice of polymer types is available in latex form, usually at relatively high molecular weights which tend to provide good physical properties in polymer films.

The same characteristics which make latices so attractive also are at

the root of the basic problem of "in situ" film formation with these materials: (1) ready dispersibility in the aqueous environment, and (2) built-in stability to prevent latex coagulation during manufacture and handling. Much of the laboratory work with latices was directed at overcoming these problems. Other considerations included the optimization of physical and especially barrier properties. Compounding for increased density to counteract buoyancy is generally required for most polymer films. However, this is usually more easily achieved in latices compared to melt or solvent systems.

Polyvinylidene Chloride

This polymer is known for its excellent barrier properties to gases and vapors and is therefore widely utilized in the packaging field either as a base film or as a coating for less expensive films. Since diffusion in the gaseous and liquid phase are basically similar processes, it was expected that this polymer could produce a good barrier to mercury compounds. This material is also largely unaffected by water and has one of the highest densities of commercial polymeric products. Both of these factors should contribute to producing a good barrier film, and the high density eliminates the need for fillers to overcome buoyancy. From the chemical structure of this polymer good resistance to the aqueous and biological environment may be predicted, which should result in a long service life. At the same time no toxic contaminants are expected to be released into the environment.

A commercial, high solids (61 percent), polyvinylidene chloride latex, Daran 220, was selected for the laboratory investigation. This latex has an initial pH of 3.5 to 4.5 which may drop further on aging. It was, therefore, believed that an alkaline coagulating solution might be best suited to produce films. Films were cast on glass substrates with 40-mil draw down bars. The wet films were immediately immersed in a tray filled with the coagulating medium, and after 5 minutes the product was transferred to a water bath.

According to the results summarized in Table A-2 (in the Appendix), a 20 percent sodium hydroxide solution, contrary to expectation, did not produce a good film. A hydrochloric acid solution of the same concentration, however, gave very encouraging results. Unfortunately, reduction of the acid concentration to 5 percent produced a very weak film, indicating that a very short contact time encountered in an actual operation would require considerable alteration of the latex properties to overcome its stability. Other effective coagulant baths included 20 percent solutions of aluminum sulfate and of ferric chloride respectively.

In addition to the need for reducing the coagulation time, two shortcomings requiring attention were identified by the above tests: (1) the surface of the wet films was distrubed to a considerable depth by the immersion into the coagulation baths (identified as "rough surface" in the tables), and (2) all films were somewhat brittle; those coagulated with HCl to a lesser degree than those contacted with the other baths.

The remaining experiments shown in Table A-2 were designed to deal with several of the problems identified above. The colloids shown in the table include several grades of alginates, some polyanhydride resins and vinyl acetate copolymer. Several of these colloids were quite effective in eliminating the surface roughness described above. The alginates in particular produce very high viscosities in aqueous systems even at 1 or 2 percent concentration. The effect of increasing the viscosity of a latex system is to reduce the mobility of the liquid film during the crucial moments when coagulation is initiated. Moreover, the alginates, and some of the other colloids as well, are gelled by acids or polyvalent cations (including Al^{+++} and Fe^{+++}). These chemical reactions occur much more rapidly than the physical process of particle coalescence involved in the coagulation of the latex. Thus a colloid-thickened latex film on contact with the coagulation medium becomes almost immediately embedded in a gel structure which provides the environment in which the latex coagulation can proceed.

Of the several colloids tested, the alginates gave the best results. There were also small differences in film strength discernible in compositions containing different grades of alginates. In general, it was concluded that an alginate concentration between 0.5 and 1 percent based on latex solids gave optimum results and that Superloid was the preferred grade.

Efforts next turned to reducing the brittleness observed in the Daran films. The experiments in Table A-3 (in the Appendix) summarize the progression of this work. From the outset it was discovered that many of the recommended plasticizers affected the latex stability adversely (see 31 series). This behavior, if properly controlled, could be turned into an asset by improving the response of the latex to the coagulation media. Based on the results of the early experiments subsequent work concentrated on the use of Santicizer E-15 as the plasticizer.

A plasticizer concentration series (36-1 to 36-4 in Table A-3) indicated that levels of 20 percent or higher based on polymer would coagulate the latex. Later work in the presence of colloid showed that 20 percent plasticizer levels could be tolerated. This level of plasticizer was also desirable from the standpoint of flexibility as well as for any increase in coagulability it may have provided. Comparison between films coagulated with hydrochloric acid or aluminum sulfate showed that the latter were distinctly harder and less flexible despite the high plasticizer content.

Some laboratory work was also conducted in an attempt to predict the minimum contact time between the latex composition and the coagulating solution. For this purpose, cast films were exposed from 2 to 5 seconds to the coagulant baths and immediately transferred into water. Examination of the strength of the surface skin was used as the basis for judging the minimum contact time probably necessary for satisfactory film generation. It was estimated that a minimum of 3 seconds contact with 20 percent HCl may be desirable and perhaps somewhat less for more

concentrated solutions. On the other hand, both 20 and 40 percent aluminum sulfate solutions gave less satisfactory results. In comparison with the other latex systems under investigation, the Daran based compositions continued to hold the greatest overall promise of success.

Styrene-Butadiene

Among a group of latices surveyed, a carboxylated, 50/50 styrene-butadiene latex, FR-S 257 showed promise for underwater film generation. Film formation occurred with 20 percent solutions of HCl, $FeCl_3$, or $Al_2(SO_4)_3$. The results given in Table A-4 (in the Appendix) show that the products formed in HCl had superior properties, and this conclusion was repeatedly confirmed with later compositions incorporating various colloids. The use of colloids was necessary just as in the case of the Daran latex in order to protect the wet film from disruption on immersion into the coagulants.

Unlike Daran, this polymer did not require any plasticizer to produce flexible films. However, its density was sufficiently low to require the incorporation of a filler to keep the film from flating to the surface. Titanium dioxide was stirred into the composition at a 10 phr (parts per hundred rubber or polymer) level and performed this function satisfactorily. In a large-scale operation a less expensive filler such as clay or barytes could be substituted. In our laboratory experiment the TiO_2 helped make the uniformity of dispersion more visible. Grinding of the filler is not necessary, unless long storage life is desired, since the unground filler would settle considerably faster.

The disadvantages of films coagulated from FR-S 257 were mainly their softness and inadequate strength. As a corollary, much longer contact times with the coagulation media were necessary to develop coherent self-supporting films. The experimental work to correct these shortcomings included the evaluation of several colloids in addition to the alginates. Some of these were employed in much higher concentrations in order to produce a maximum effect on the physical properties of the films. Some compositions were formulated with carboxymethyl-cellulose, since this hydrocolloid was expected to add hardness and physical strength to the films, particularly when treated with aluminum sulfate. In order to introduce larger quantities of colloids into the formulation, recourse was taken to lower molecular weight products. In general, the results did not indicate sufficient improvement to justify further development of this system, although some gains were made with aluminum sulfate coagulation of a composition containing Kelgin LV (see 42-6 in Table A-4).

Some formulations were also prepared containing such potential mercury scavengers as sulfur or zinc. Sulfur presented a special problem because of its very poor water wettability. However, this could be overcome by treating the sulfur powder with a surface active agent before incorporation into the compositions. It was hoped that the polymer matrix surrounding the zinc particles would protect them at least for a brief contact time from the effects of a dilute hydrochloric acid bath. However,

hydrogen formation resulting in numerous bubbles in the film could not be prevented. It will be necessary, therefore, to avoid this combination.

An unmodified synthetic rubber latex, FR-S 194, consisting of a 26/74 styrene-butadine ratio was investigated as outlined in Table A-5 (in the Appendix). Hydrochloric acid coagulation of the latex by itself resulted in much shrinkage. This could, however, be eliminated by adding a small amount of alginate. Concentration studies with several alginates showed that lower concentrations tended to give stronger films. However, the shrinkage and surface roughness described earlier limited the amount of reduction that could be tolerated to between 0.5 and 0.8 percent based on latex solids. Further study of this system was discontinued because no improvement in coagulation time or in film strength over the previously described formulations was obtained.

Miscellaneous Latices

In addition to the systems discussed in the previous sections, a number of other latices were briefly examined (see Table A-6 in the Appendix). Two of these were synthetic rubber latices and three others were vinyl chloride-based polymers or copolymers.

The rubber latices consisted of a 29/71 styrene-butadiene polymer, FR-S 2003, and a polybutadiene, FR-S 2004. Neither of these products showed promise for any improvement over the other rubber latices which were studied at greater length. They were consequently dropped from the program.

The remaining polyvinyl chloride (PVC) latices are chemically more closely related to the Daran latex than to the rubber latices. The first one shown in Table 5, FPC 790, is an unplasticized homopolymer which does not lend itself readily to film formation without further modifications, as is borne out by the results. According to the manufacturer's recommendations it requires high plasticizer levels to improve properties. While some improvement in film quality was realized in laboratory experiments, the results fell considerably short of what was needed.

A PVC latex preplasticized during manufacture with 35 parts dioctylphthalate, FPC 7299B, produced considerably better results, particularly when HCl was the coagulating agent. However, these results seem to depend on fairly long contact time with HCl, and considerably more compounding would be needed to shorten this time. In contrast, a vinyl chloride-acrylic copolymer latex, FPC XR 7351, produced interesting results in relatively short contact times, once it was modified by a colloid and a plasticizer. This compound responded especially well to coagulation media of higher acid content such as 50 percent sulfuric acid.

While these results point to some interesting directions for further study, it was felt that the program objectives could be more easily achieved with one of the other, more simple approaches. Further work with latices was, therefore, suspended.

Solvent Systems

From the standpoint of ease of film formation, polymers soluble in water-miscible solvents are particularly attractive. The water environment acts directly as the coagulating medium, greatly simplifying the delivery system and eliminating the problems of contact time with the gelling agent encountered with the latices. However, there are also two inherent disadvantages associated with such systems: (1) the solvent will contribute to the BOD and in some cases may be toxic and (2) viscosity considerations will restrict the maximum polymer content below that possible with most latices.

To explore the possibilities of such a system, an alcohol soluble nylon terpolymer, Elvamide 8061, was selected. This polymer is known to produce strong, tough films, and its solubility in alcohol-water mixtures was expected to minimize the toxicity and BOD problem. Solutions were prepared by refluxing the resin in the solvent for 2 to 3 hours. Both methanol and ethanol could be used in combination with 10 to 20 parts water. Eventually, however, ethanol-water systems were preferred in order to further minimize toxicity.

As shown in Table A-7 in the Appendix, solutions of 10 percent nylon concentration were originally prepared. However, these formulations suffered from a disruption of the film surface similar to that encountered with unmodified latices. An attempt to overcome this difficulty by incorporating a viscosity modifier, Avibest, was partially successful. However, the preferred approach was to increase the viscosity by raising the polymer concentration to 25 percent. These formulations gave generally satisfactory results. However, to prevent flotation during the period before most of the low-density alcohol was leached out of the film, it was necessary to add fairly high levels of fillers. Eventually, for the tank experiment, the expensive TiO_2 was satisfactorily replaced by barytes.

The feasibility of this system has been established and its usefulness will depend primarily on its comparative cost effectiveness and on the evaluation of the possible environmental impact of the alcohol.

Hot Melt Materials

Hot melt compounds are essentially 100 percent solid materials which become sufficiently fluid at elevated temperatures for application to various substrates. Blends can be formulated to give various properties as required by the end use. The primary advantage of hot melts is that they eliminate the use of solvents during shipping and storage, thereby reducing fire hazards and toxicity problems. The successful use of these compounds depends largely upon a combination of properly formulated materials and the development of suitable application equipment.

For the purpose of this program it was anticipated that the hot melt would be extruded directly into water to form a barrier film. Furthermore,

it was visualized that the melting of the compound would be accomplished on board a surface craft and the melt pumped through a hose to an underwater nozzle. Since a low-melting compound would reduce the complexity of the equipment, it was decided early in the program that the hot melt should have a low melting point (preferably in the 200 to 250 F range) and a low viscosity. These requirements restricted the number of candidate polymers to some extent.

Polymers

Hot melts can be considered as consisting of three major components as shown in Figure 8. A number of elastomeric polymers whose properties made them suitable candidates for this program are commercially available. Among those selected for study were (a) ethylene/vinyl acetate (EVA), (b) ethylene/ethyl acrylate (EEA), (c) ethylene/acrylic acid (EAA), and (d) polycaprolactone (PCL).

Both EEA and EVA polymers showed promise as base resins for hot melt films. EAA also showed promise. However, because of its high melt viscosity and high cost, only a limited amount of work was done with it.

The ethylene copolymers are available in a range of melt indices (MI) which, in turn, is the weight of resin extruded per unit time under standard temperature and pressure. Thus, a low MI indicates high melt viscosity. Conversely, a high MI shows a low melt viscosity. Work with these copolymers indicated that within a given class of resins, superior films could be obtained with those having a low melt index. However, the higher melt viscosities would necessitate higher extrusion temperatures.

Polycaprolactone (PCL) formed strong, flexible films. Although the melting point is low (60 C), its melt viscosity is high. As a result, high temperatures were necessary for smooth castings. Attempts to reduce melt viscosity by blending with modifying agents were not successful due to incompatibility of the selected materials. Later it was noted that the PCL films became quite brittle with age. Because of these factors, work with this particular compound was discontinued.

Viscosity Depressants

Viscosity depressants help lower the viscosity and softening points of hot melt blends. An extremely large number of these compounds are commercially available. Those selected for study in this program were hydrocarbon resins, mineral oil, and asphalt. The hydrocarbon resins included vinyl toluene copolymers and low molecular weight polystyrenes. The compound showing the most promise was Klyrvel, believed to be a low-molecular-weight polystyrene. Based on a limited amount of work, it appeared that up to half of the polymeric component could be replaced with this resin without seriously affecting the properties.

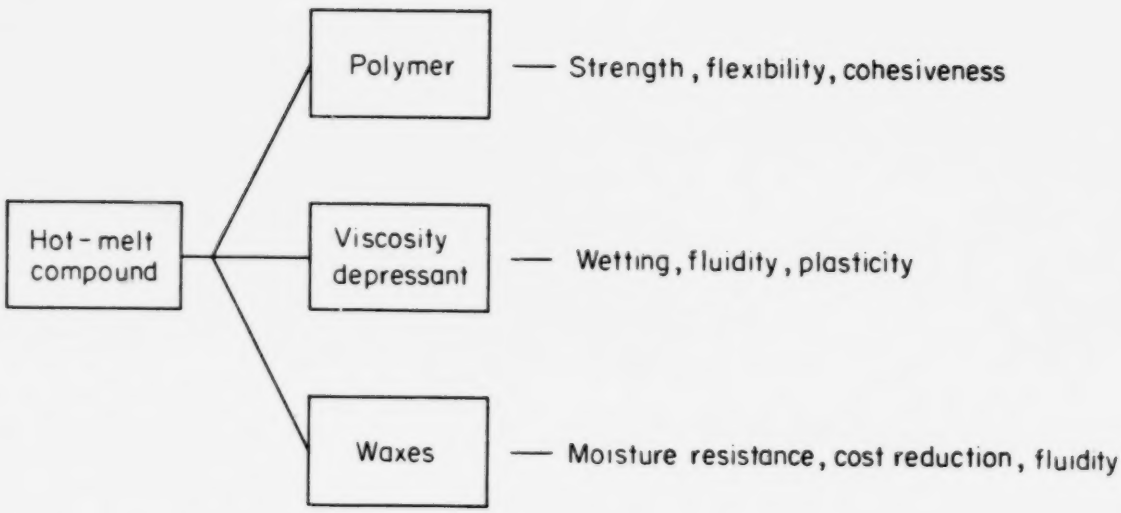


FIGURE 8. EFFECT OF COMPONENTS ON PROPERTIES OF HOT-MELT COMPOUNDS

Mineral oil, at 15 percent concentration, helped reduce melt viscosity of EVA-based blends but also cuased a noticeable reduction in strength. No further work was done with this material.

Only a limited study was made with asphalt compounds. The addition of asphalt to EVA blends produced a very soft, tacky film. In addition, wax did not appear to be compatible with this system.

Waxes

Waxes provide viscosity control for hot melts at elevated temperatures and help reduce costs. Both paraffinic and microcrystalline waxes were included in this study with the former showing the most promise. In general, it was found that (1) up to 50 percent wax could be used without seriously reducing strength properties, and (2) the lower melting point waxes were superior to those with high melting points.

Hot Melt Blends

A large number of low-melting blends were evaluated for potential use as barrier films. Criteria for use were low melting and low melt viscosity. The results of tests on these experimental compositions are summarized in Table A-1 in the Appendix. Since physical requirements for these materials have not been fully established, the data in the table are qualitative and for comparing one composition against another. The formulations and characteristics of two compounds showing the most promise are listed in Table 1. Continuous films were prepared on the continuous draw down roll using these two formulations.

These two blends were variously modified by the addition of (a) 10 parts of sulfur, (b) 20 parts of zinc dust, and (c) 20 parts of barium sulfate. These fillers were used, not only to increase the density of the films, but also as possible mercury scavengers. Films of these compounds were also successfully prepared on the continuous draw down apparatus. Although the tear strength was somewhat reduced, the overall properties appeared to be adequate for use as barrier films.

MATERIAL EVALUATION

Material evaluations consisted of dialysis experiments to measure barrier effectiveness and microbiological-biological evaluation of the candidate barriers.

Dialysis Experiments and Analytical Procedures

To measure effectiveness of the various plastic barriers in retaining mercury, permeability measurements had been proposed with aqueous

TABLE 1. CHARACTERISTICS OF SELECTED HOT MELT BLENDS

Composition					Viscosity		Film Characteristics						
Sample Number	EVA 505	DPD[a] 6169	Wax A-143	Klyrvel 60	F	cps	Film Thickness, mils	Flexibility	Crease Resistance	Tear Strength	Drape	Appearance	Raw Material Costs, ¢
28-3	25	---	50	25	202	8,800	8	G	G	F	Medium	Hazy	$0.28
29-1	---	25	50	25	201	20,800	8	G	G	F	Medium	Hazy	$0.22

(a) Ethylene ethyl acrylate

solutions of inorganic and organic mercury compounds using known concentrations. Some tests were also conducted later in the program with mercury-contaminated sediments under aerobic and anaerobic conditions.

Dialysis cells were constructed of size 40 o-ring tubes having 4.2 inches inside diameter (see Figure 9). The film samples of 13.8 cm^2 effective area were sealed with rubber gaskets of 1/8-inch diameter. The whole assembly was held together by means of plexiglass plates which clamped the opposite portions of the cell together and were fastened with screws on the four corners of the plates. The bottom part of the cell was closed off near enough to the film to permit strong agitation which was obtained with a magnetic stirrer. A side arm permitted venting of any air entrapped underneath the membrane and could also be used as an entry port to remove samples, as the occasion arose.

The original goal of determining rate constants for the plastic films had to be modified when it was shown early in the program that both inorganic and organic mercury species were readily absorbed by the glass and plastic surfaces with thich they came in contact.

As recommended by the Project Monitor, the analytical procedure adopted throughout this program is based on flameless atomic absorption. The method according to Storet No. 71900 and No. 71890 was followed. The limit of detection achieved in aqueous samples was 0.2 μHg/l.

Problems were also encountered in the analysis of film samples for mercury content. Since the recommended procedure did not disintegrate most of the plastic films, there is no assurance that all of the mercury in these films was detected. The main exception to this conclusion is the nylon 6 film which completely dissolved in the nitric acid. The hot melt compositions, although melted down during the digestion procedure, remained in a separate, immiscible phase, and therefore, could possibly have trapped some of the mercury content. With the exception of the nylon 6 film, the analytical data for the mercury content of other membranes are suspect and have generally not been used to derive conclusions.

On the other hand, the analytical technique was able to detect mercury levels in aqueous solutions down to a concentration of 0.2 μgHg/l. The most significant data from the dialysis runs, therefore, are the mercury levels found on the distilled water side of the films, across from the mercury test solutions. Barrier screening tests were conducted over night for 15-hour periods and the solutions were analyzed the same day the test was completed to minimize mercury absorption on the container surfaces.

Preliminary screening tests with mercuric chloride ($HgCl_2$) solution showed no detectible levels in the distilled water across the sample. A long-term test was conducted, therefore, for a little over one week. Again, as the data summarized in Table 2 indicate, no detectible transfer of mercury across any of the films occurred. It should be noted that the test with nylon 6 was run for 15 hours only. However, the $HgCl_2$ level of the test solution was doubled to accelerate the dialysis.

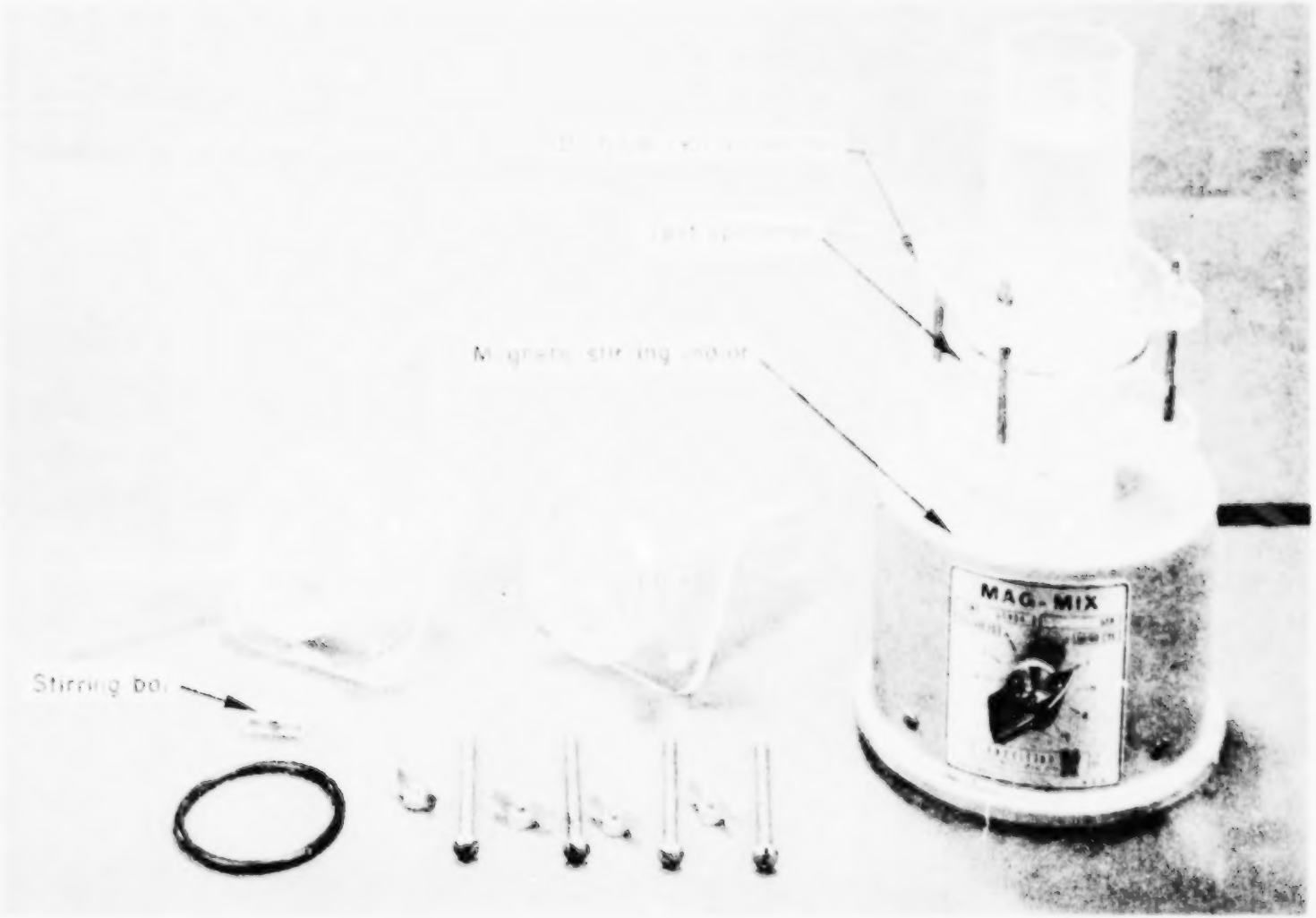


FIGURE 9. DIALYSIS-CELL APPARATUS

TABLE 2. TRANSMISSION OF INORGANIC AND ORGANIC MERCURY THROUGH POLYMERIC FILMS

Films	Film Thickness, mils	Long Term Dialysis[a] $HgCl_2$ Transmission[b]		Short Term Dialysis[a] $HgClCH_3$ Transmission[b]		Short Term Dialysis[a] $Hg(CH_3)_2$ Transmission[b]	
		μgHg/ℓ	% of Test Solution	μgHg/ℓ	% of Test Solution	μHg/ℓ	% of Test Solution
Generated In Situ							
Hot Melt 35-1B	8.5	<0.2	<1.5	0.44	3.3	1.2	9
Elvamide 72-3	21	<0.2	<1.5	<0.2	< 1.5	0.22	1.6
Preformed							
Low Density Polyethlene	4	<0.2[c]	<1.5[c]	2.2	16	0.8	6
High Density Polyethylene	2	<0.2	<1.5	0.4	3	0.32	2.4
Polyvinyl chloride	4	<0.2	<1.5	1.0	7.4	0.32	2.4
Nylon 6	2	<0.2[d]	<0.75[d]	<0.2	< 1.5	<0.2	<1.5

(a) Long term dialyses were carried out for one week; short term dialyses were carried out for 15 hours.

(b) Initial concentrations of test solutions were 20 ugHg/ℓ except where noted otherwise; calculations of % Hg transmission were based on the initial concentration.

(c) This test was conducted for 4 days.

(d) This test was conducted for 15 hours with a test solution of 40 ugHg/ℓ initial concentration.

Shorter evaluations were also carried out with these same films using methylmercuric chloride, ($HgClCH_3$), and dimethyl mercury, [$Hg(CH_3)_2$], solutions. Unlike the tests with the inorganic mercury, transfer of the organic species was demonstrated in all but one of the films. In comparing the data in Table 2, the reader is cautioned to take account of the differences in thickness between the films. The preformed films were evaluated at thicknesses that will most likely be employed in the field, the differences generally depending on the commercial availability and the physical strength of the barriers. The hot melt and Elvamide films, which would be generated "in situ", were tested at greater thicknesses than the preformed films, since the production of 2 to 4-mil films may not be practical under water.

The most important conclusions that can be derived from the data in the table are

(1) Nylon is the best barrier of all the films tested both for inorganic and organic mercury compounds.

(2) High-density polyethylene is the next best barrier material.

(3) Organic mercury compounds tend to pass through most plastic films more rapidly than the inorganic form.

Within the limits of these tests, a very good probability for successfully containing mercury in contaminated sediment seems to have been demonstrated.

Some dialysis experiments with hot melt compositions incorporating such potential mercury scavengers as sulfur or zinc were also carried out. However, the results remained inconclusive because of the difficulties encountered in analyzing polymeric films. Mercury absorption data for several of the membranes such as polyvinyl chloride, low density polyethylene, and hot melt compositions strongly suggest that mercury absorption may be a feasible alternative to containment, should this ever become the preferred procedure.

Some dialysis runs were also undertaken with hot melt films employing mercury contaminated sediment as the dialysis medium. A strongly contaminated sediment was obtained for this purpose and was slurried to a fluid condition with 10 parts distilled water. One portion of this slurry was aerated with oxygen over night, and the other one was refluxed for the same period to drive off gases. The mercury content of the oxygenated sample was 29 ppm and that of the boiled sample was 23 ppm. The difference may be considered to reflect the loss of volatile mercury compounds. The mercury was present largely in water-soluble form as indicated by a mercury content of the supernatant liquid of the original sediment of 17.3 mg/l. Mercury transfer from the oxygenated mud through the hot melt film was 0.11 µgHg and from the boiled mud 0.03 µgHg. This reinforces the conclusion that a volatile, probably organic, form of

mercury was lost from the boiled sample, and that this form preferentially permeated the hydrocarbon film. From the information in Table 2, it may be inferred that a nylon film would most probably have contained the mercury in the sediment.

BOD Experiments

Three types of laboratory and one field evaluation were undertaken on seven candidate barrier polymers. Biochemical oxygen demand (BOD), bacterial growth in water containing leached polymer specimens, and associated evaluations on polymer leach water (dissolved oxygen or DO, total carbon or TC, and pH) were conducted to determine whether there might be adverse environmental effects in waters where the barrier films are applied. Laboratory evaluation against fungi and freshwater exposure to bottom organisms were initiated to allow an estimation of whether the films are resistant to fungal or invertebrate degradation and will therefore have a reasonable period of performance. Specimens of the polymers were cut to appropriate sizes as follows:

Leaching - 5 x 10 cm (also used in bacteriological study)

Fungal Study - 5 x 5 cm

Field Study - 7 x 7 cm

At least three replicates were prepared for each type of specimen.

The leaching water used was the PAAP medium (see reference 3 in Section VII). This is a balanced minimal salts medium containing a total of 85.7 mg/l of mineral salts. Distilled-deionized water of high purity (1×10^6 ohms cm) was used in preparing this medium.

The BOD procedure was the one outlined in Standard Methods (see reference 4 in Section VII) except that a special electrode (YS Instrument Company, self-stirring BOD bottle probe) was used to measure DO. A radiometer pH meter with pencil electrode was used to measure pH, and a Beckman Infrared Carbon Analyzer was used to measure total carbon (TC).

The bacteriological study consisted simply of replacing leach water (removed for BOD and other evaluations) with equal amounts of water medium, inoculating with sewage seed at essentially the rate employed for BOD (0.1 ml/100 ml), and estimating initial and final (48 hr) cell numbers by standard petri plate counting procedure.

The petri plate procedure for the fungal evaluation is described in CCC-T-191b (see reference 5 in Section VII) with the inclusion of an additional nutrient medium to compare with the non-nutrient mineral salts agar medium (MSA). Spray inoculation (approximately 0.4 ml of an inoculum containing 2×10^4 fungal spores per ml) of polymer specimens was accomplished with a No. 82 Devilbiss atomizer. The 7 day fungal cultures used in preparing the inoculum were Aspergillus niger, A.

terreus, Chaetomium globosum, and Penicillium citrinium. Stock cultures were maintained on PDA test tube slants. The inoculated specimens were incubated at 25 C and observed for fungal growth after one week.

Exposure of the seven polymers to freshwater bottom organisms was accomplished by means of Hester-Dendy multiple plate samplers (see reference 6 in Section VII). The samplers were composed of 7 x 7 cm masonite plates mounted alternately with 2.5 x 2.5 cm masonite spacers on 10 cm stainless steel eyebolts and held tightly in place by means of stainless steel nuts. Duplicate polymer specimens (7 x 7 cm) with a center hole to fit the eyebolt were placed on either side of seven spacers with plates on both sides of the specimens. Four sets of samplers were then placed in shallow water (approximately 4 feet depth) in Battelle's research lake. One sampler was to be removed after two weeks, and others after one, two, and four months of exposure. The results of these studies to date are presented in Table 3.

The following comments on polymer performance can be made.

(1) On the basis of minimal changes in pH, DO, and BOD, and limited TC addition to the leach water, the polyethelene, hot melt, and PVC polymers appear to be most promising candidates. However, all may be susceptible to attack by fungi, and components of the hot melt polymers supported increased bacterial growth after initial leaching. Data on bottom organism attachment and growth are not conclusive at this time.

(2) Keltex (alginate) disintegrated after short periods of time in water, drastically lowered pH, and contributed significant TC to leach water. For these reasons, this polymer cannot be considered for extended bottom life application.

(3) The negative results obtained with alcohol soluble nylon film prepared "in situ" in which the polymer made a high TC contribution to leach water (see results for alcohol soluble nylon solution), are a reflection of the beaker scale experiment; at much greater dilution in a lake, the effects may be negligible. The difference in TC and BOD values for alcohol soluble nylon solution (5575.0 mg/l and 6.1-7.2 mg/l, respectively) may indicate that the leached-out components of this polymer are toxic or at least not fully utilizable by the sewage seed bacteria at the concentration prevailing in the experiment.

Although slight colonization of organisms including snails, oligochaeia, and larvae of odonate and diptons on masonite plates in the Hester-Dendy samplers was observed after two weeks of exposure, no organisms had

TABLE 3. RESULTS OF MICROBIOLOGICAL AND RELATED STUDIES OF POLYMER BARRIERS

Code Designation	Leachate						Film			
	pH	Total Carbon mg/ℓ.	Initial Dissolved Oxygen, mg/ℓ.(b) Undiluted	1:10	Biochemical Oxygen Demand, mg/ℓ. Undiluted	1:10	Bacterial Growth, 48 hr(c)	Fungal Growth 7 day(d) MSA	PDA	Bottom Organism Growth 14 day(e)
Blank	7.1	8.8(a)	8.3	9.3	- 1.3	-	-	--	--	--
High density polyethylene	7.4	8.8	8.2	8.6	3.0	2.0	-	-	±	--
Preformed low-density polyethylene	7.0	8.1	8.1	8.6	2.9	1.0	-	-	±	--
34-1 (hot melt composition)	7.3	7.1	8.0	8.8	1.8	0	+	±	+	--
35-1 (hot melt composition)	7.2	7.7	8.0	8.8	2.2	0	+	±	-	--
2% Keltex (alginate)	3.5	905.0(f)	8.1	8.7	0.8(g)	0	-	+	++	--(h)
Nylon film	6.4	16.1	8.1	8.8	6.6	4.0	-	-	++	--
Alcohol soluble nylon solution	6.7	5575.0(f)	7.6	8.7	6.1(g)	7.2	-	--	--	--
Polyvinyl chloride	7.1	9.1	8.1	8.9	3.6	1.0	-	-	-	--
Filter paper	--	--	--	--	--	--	--	++	++	--

(a) Value for blank resulted probably from dissolved CO_2. Other values were not corrected for this. The reasons for lower TC values than obtained for the blank are not immediately apparent.

(b) Taken immediately after leaching (see text). Determinations were taken at 76 F for undiluted leachates--blank value was approximately 90% of oxygen saturation. Chilled dilution medium caused lowering of temperature to 66 F; blank value for 1:10 dilution was also approximately 90% of oxygen saturation

(c) -= no or slightly increased bacterial growth ($<2 \times 10^6$ cells/mℓ), and += significantly increased growth ($>2 \times 10^6$ cells/mℓ).

(d) -= no visible fungal growth on specimen, ±= slight growth, += moderate growth, and ++= profuse growth covering entire specimen.

(e) Only slight bottom organism activity to date. Evaluation continuing.

(f) Sample diluted 1:100 because of high TC (values corrected for dilution).

(g) Bacterial growth (and oxygen utilization) were apparently limited by low pH or soluble polymer toxicants.

(h) Completely disintegrated.

attached to the polymer specimens. Keltex (alginate) had disintegrated during the two week exposure period.

EQUIPMENT EXPERIMENTS

Experiments were carried out with most of the material systems as they were developed in the laboratory. The primary means of evaluation was with a small scale test tank into which overlay of one or two feet in width can be deployed. The tank is 18 feet long, 3 feet wide, and 20 inches deep. Rails are installed at the top edge of the tank so that a carriage which holds test apparatus and experimental dispensing means can be moved along the length of the tank. In addition to this apparatus, The Battelle Ocean Research pool and a Columbus Recreation Department swimming pool were used for large scale evaluations of preformed film experiments.

Experimental equipment was developed and experiments were conducted throughout the program with all of the candidate material systems.

Equipment for Coagulable Materials

A one-foot-wide nozzle was designed and constructed for experiments with coagulable materials. Polymer was supplied to the nozzle with a positive displacement rotary screw pump and acid solution or other gelling agents were supplied by a self-priming flexible impeller pump. Supply tanks and pumps are mounted on the carriage which fits on the test tank. Figure 10 shows how this apparatus is arranged on the test tank.

The nozzle is designed so that the polymer and gelling agent can be co-extruded into the water. Figure 11 is a schematic cross section through the nozzle which shows this relationship. The polymer exit and the top gelling agent exit is shown in Figure 12, a photo of the exterior of the nozzle.

The design of the one-foot-wide nozzle is very similar to that used for producing polymer film in a program for the Supervisor of Salvage, U.S. Navy, several years ago.

The initial experiments with the one-foot-wide nozzle were made with sodium alginate polymer and a 10 percent HCl solution gelling agent. Satisfactory results were obtained, and experiments proceeded with other coagulable materials.

Coagulable Latex Compositions

At the very beginning of this research, an experiment was conducted with a coagulable carboxylated 50/50 butadiene-styrene copolymer. This

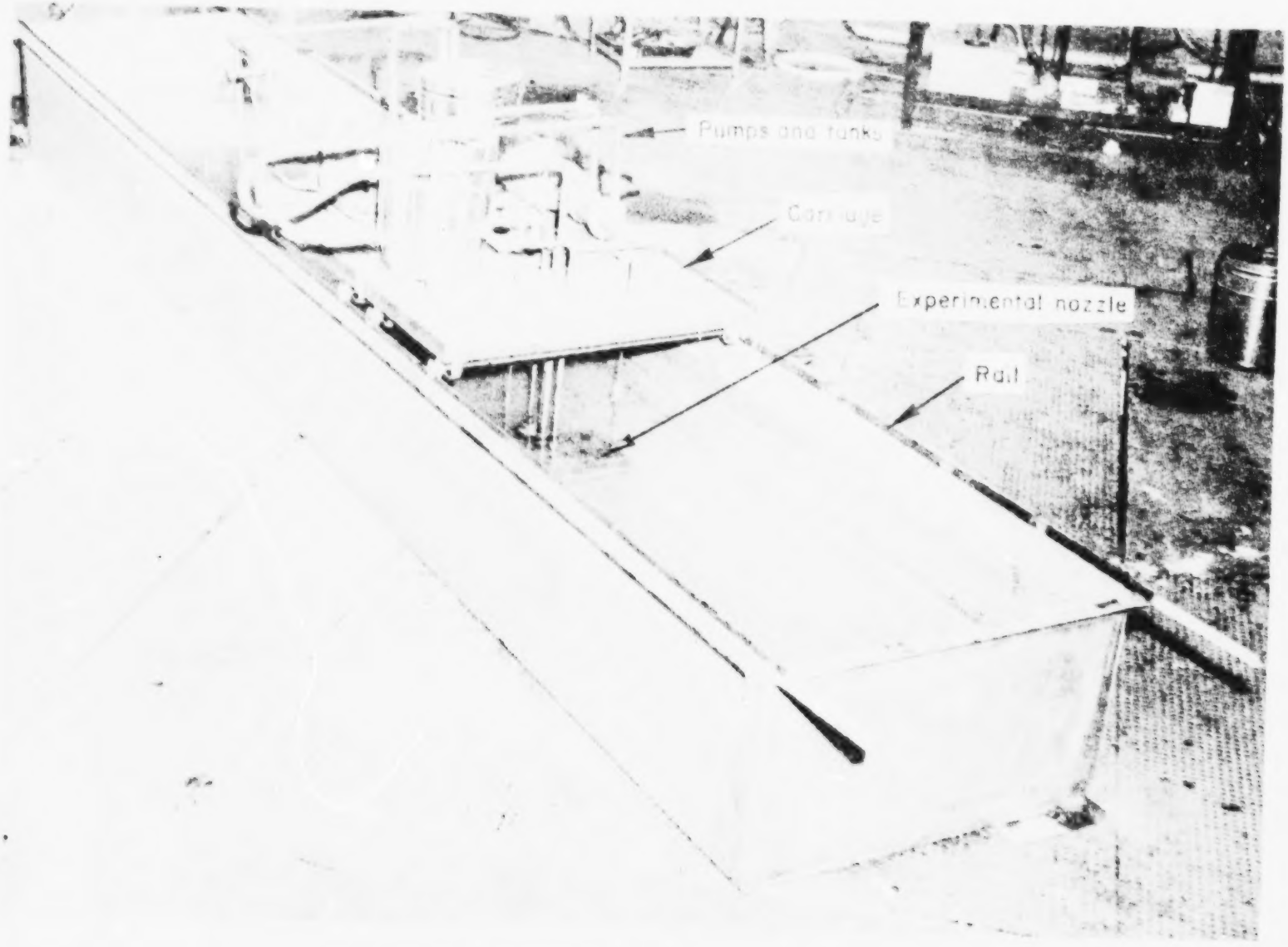


FIGURE 10. TEST TANK AND TYPICAL APPARATUS

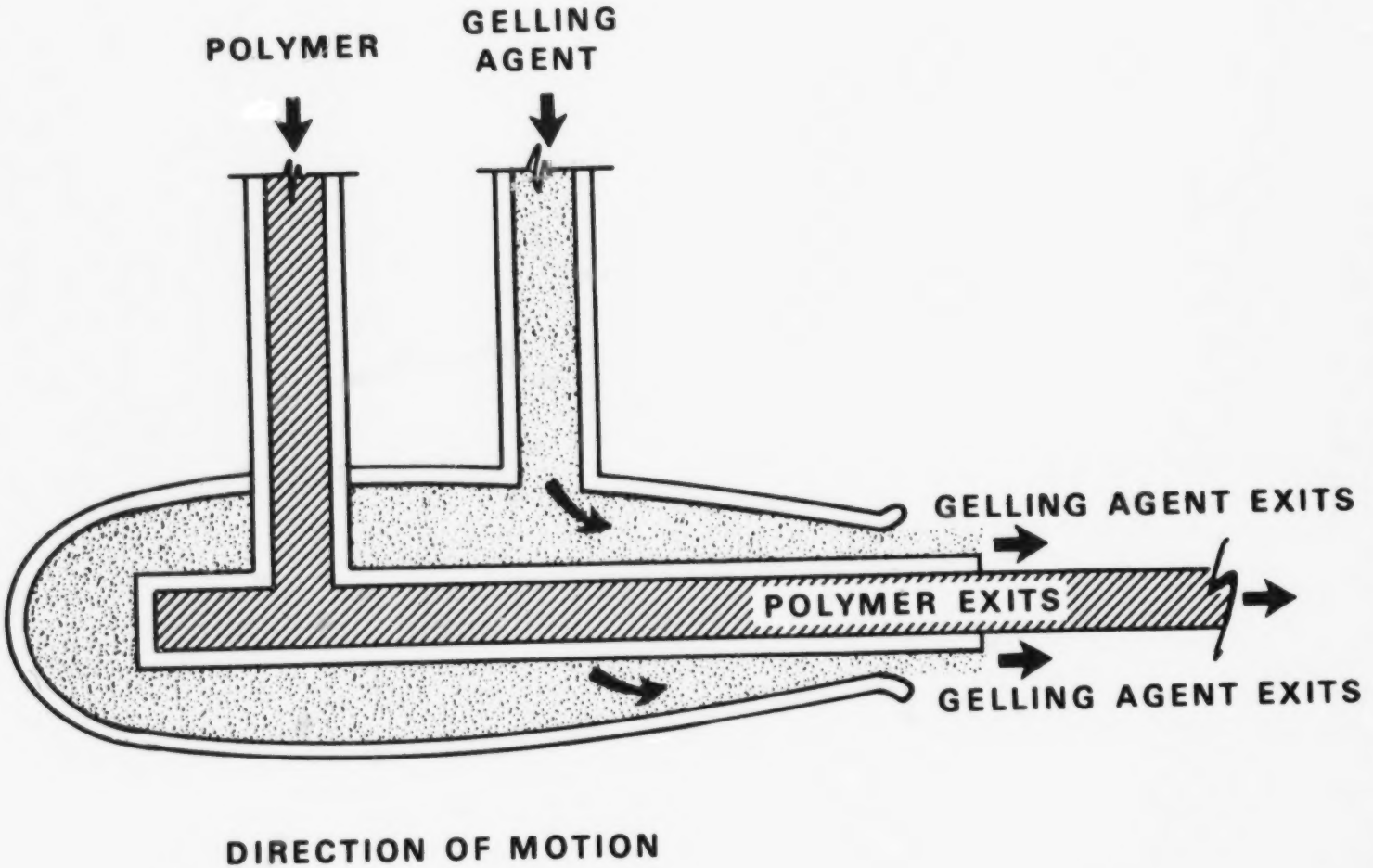


FIGURE 11. SCHEMATIC CROSS SECTION COAGULABLE POLYMER NOZZLE

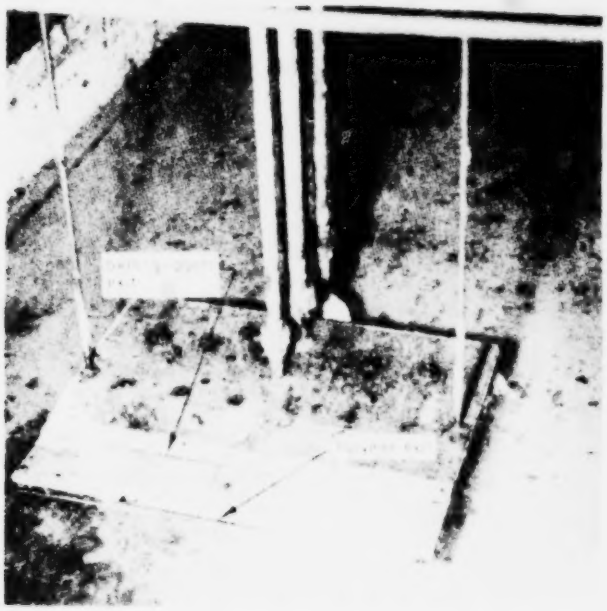


FIGURE 12. EXTERIOR OF EXPERIMENTAL COAGULABLE FILM NOZZLE

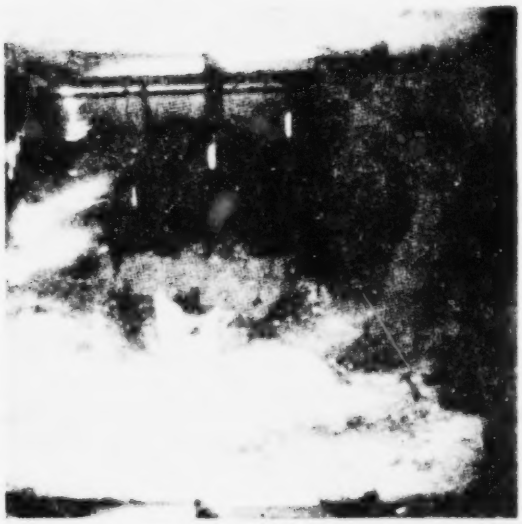


FIGURE 13. FR-S-257.BASED LATEX EMERGING FROM EXPERIMENTAL NOZZLE

consisted of latex (FR-S 257) 80 percent, Superloid (2 percent aqueous solution) 17 percent, and TiO_2 4 percent. Although a smooth coherent polymer layer was extruded from the nozzle, only a thin skin formed on the latex layer, which broke up as the material settled into the bottom of the tank. Figure 13 shows the latex film emerging from the nozzle. The water in the tank was not disturbed and no further coagulation of the latex compound occurred.

It seemed apparent that the gelling agent was not in contact with the polymer long enough and in great enough concentration to effect coagulation. The laboratory experiments had produced an exceptionally tough, solid, pliable film, but this had apparently resulted from the relatively long exposure to the HCl in the tray.

This first experiment was followed by a trial run with a similar latex system. This consisted of latex (FR-S 257 69.4 percent, Superloid (2 percent aqueous solution) 13.9 percent, TiO_2 16.9 percent. The previous experiment had been conducted with a nozzle opening of 0.125 inch; this experiment was carried out at 0.035-inch nozzle opening. It was reasoned that a thinner polymer film would effectively increase the HCl-to-polymer ratio, and that this would result in a stronger film. Unfortunately, unsatisfactory results were again obtained; that is, skin coagulation and film breakup.

Because of the above results, additional laboratory experiments were conducted in a manner intended to simulate the dilution of gelling agent experienced in the tank experiments. Latex films drawn down on glass plates were momentarily dipped into gelling agent and then immediately immersed in fresh water. It appeared from these simple experiments that 5 or 6 seconds of exposure to the HCl solution was required for most latex systems to cause sufficient coagulation to obtain a coherent film. Although only one side of the film was exposed to the gelling agent, the film thickness of the total cast film was only about 20 mils, or half of that in the tank experiments. These laboratory experiments could only approximate tank conditions but they did show that a minimum time is required to obtain coagulation with these particular rubber latices.

Laboratory work was directed toward reducing the gellation time of the polymer. Another experiment was conducted with a polyvinylidene chloride based latex, consisting of latex (Daran 220) 77-1/2 percent, Santicizer E-15 7 percent, Superloid (2 percent aqueous solution) 15-1/2 percent. A 20 percent HCl solution was used for gelling agent. The nozzle opening was set at 0.030-inch. Although bench scale experiments had indicated that a tough film could be formed with HCl, the results of the experiment were unsatisfactory with the production of only shards of coagulated latex and considerable dispersion into the water.

This experiment was followed immediately with another one using the same polymer and a 40 percent $AL_2(SO_4)_3$ solution as coagulation medium. A nozzle slit width of 0.030 inch was also used in this experiment. A substantially whole film was produced but a few inches from the nozzle the film broke and settled to the bottom of the tank. Figure 14 shows

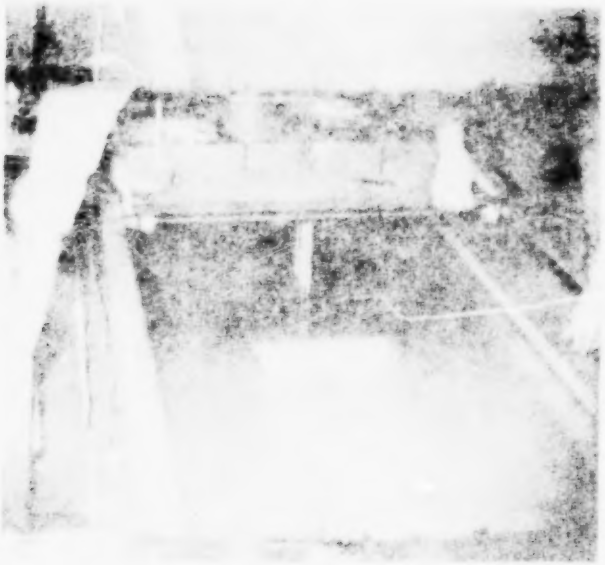


FIGURE 14. DURAN 220-BASED LATEX EMERGING FROM EXPERIMENTAL NOZZLE

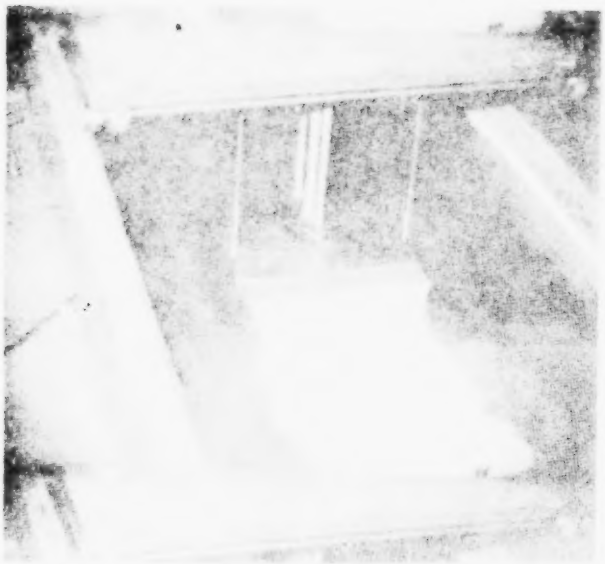


FIGURE 15. ALCOHOL-SOLUBLE NYLON EMERGING FROM EXPERIMENTAL NOZZLE

this material as it emerged from the nozzle. Note the fracture of the film a few inches from the exit. No dispersion of the polymer into the water in the tank was observed. It was noticed during this experiment that the gelling agent was not impinging on the polymer smoothly as it was co-extruded from the nozzle.

Modifications of the apparatus to incorporate shrouding which would increase the contact time of the polymer and gelling agent was considered as a possible next step. Concurrent with the work on latex-based coagulable polymers, considerable success was being achieved with simpler alternative approaches. In view of the additional complexities of the latex systems, further work on these materials was terminated.

Alcohol Soluble Nylon Films

The nylon/alcohol system is described earlier in this report. The basic film-forming phenomenon is based on the fact that water is a nonsolvent for the resin and the alcohol is water-miscible. Diffusion of alcohol out of the film and of water into the film structure produces the solid barrier.

Our experiment was conducted in the test tank at the end of the program. The apparatus was simply a slit nozzle through which the nylon/alcohol solution was extruded into the water. Although the film was somewhat nonuniform and thick because of poor extrusion, a continuous, coherent, and very tough film was formed in the tank. Figure 15 shows the alcohol soluble nylon emerging from the nozzle and Figure 16 shows the resulting film on the tank bottom after the water had been drained from the tank. It is believed that the large unbroken bubbles in the film are caused by nonuniform flow of the polymer which produced thin spots in the film solution as it was extruded from the nozzle.

Because this experiment appeared to show that this general approach was feasible, no further equipment modifications were conducted.

Hot Melt Film Experiments

Experiments were conducted with three different approaches to producing a film of hot melt material.

Direct Extrusion

It was originally thought that hot melt materials could be formed by direct extrusion into the water. A steam jacketed nozzle was designed and constructed that could be suspended from the carriage on the 18-foot long test tank. Figure 17 shows an exterior view of the nozzle and Figure 18a shows a schematic sketch of its cross section. Molten hot melt material is supplied from a heating kettle by a positive displacement rotary screw pump.

FIGURE 16. COAGULATED NYLON FILM FORMED IN TEST TANK

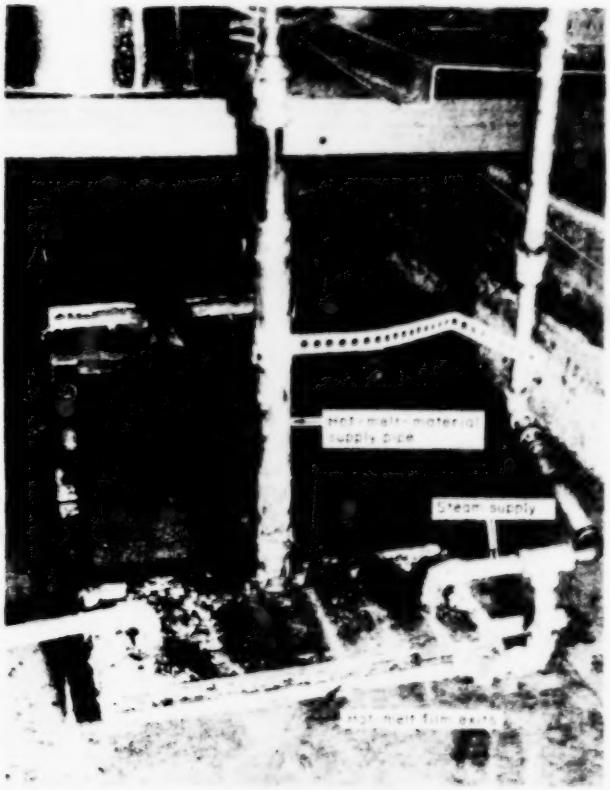
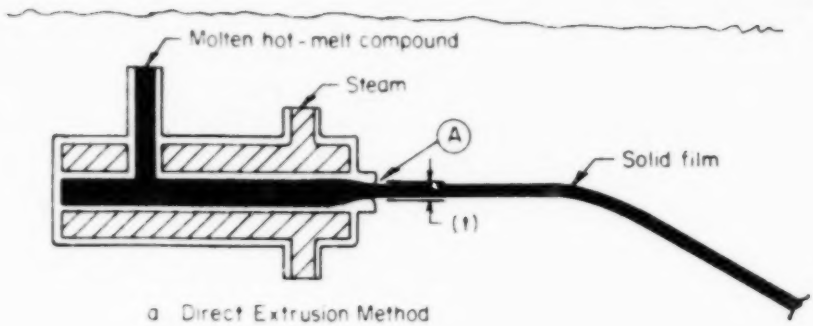
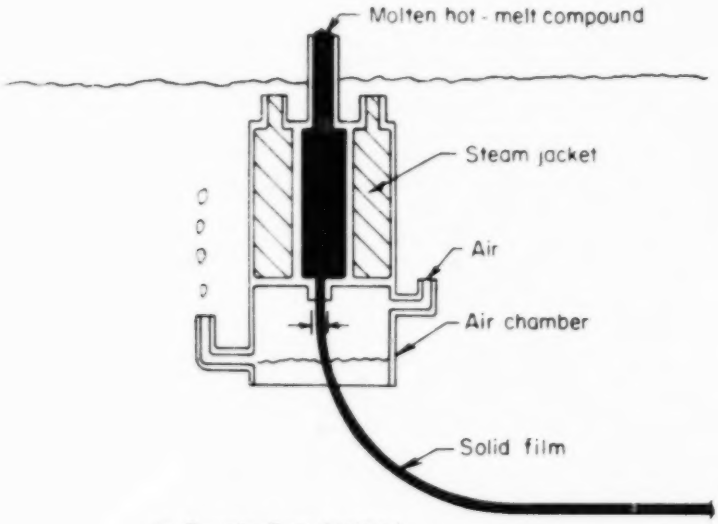


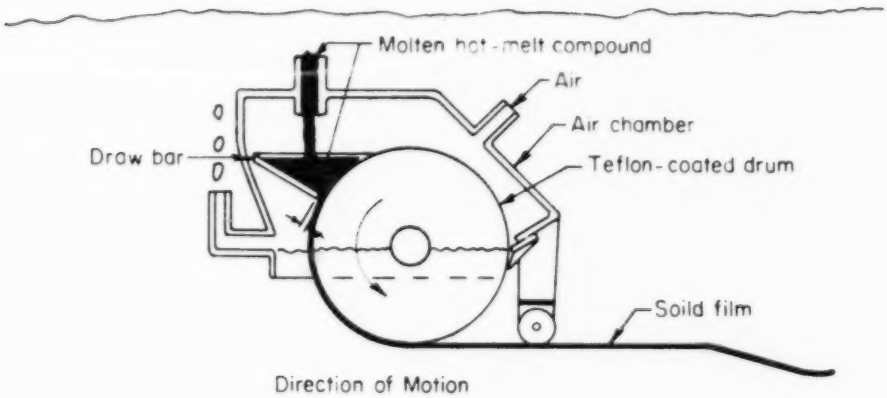
FIGURE 17. HOT-MELT DIRECT EXTRUSION NOZZLE



a Direct Extrusion Method



b Curtain Coat Method



c Continuous Draw - Down Method

FIGURE 18. HOT-MELT-COMPOUND EQUIPMENT APPROACHES

It was decided to use tuffin 30, a 30/70 copolymer of ethylene and vinyl acetate and paraffin wax in the experiments with this apparatus. This composition was used because a large supply was on hand and its fairly low viscosity and low melting point of 200 F made it ideal for handling. In our experiments with the hot melt material and the direct extrusion approach, considerable difficulty was encountered in keeping the hot melt from adhering to the lips of the nozzle; this prevented the formation of a coherent film. A large quantity of film was produced in our experiments, but most of this material was unacceptable because of the longitudinal discontinuities caused by this problem. Additionally much hand work was required in the tank to prevent the nozzle from clogging completely. A number of solutions to the problem were tried in our attempt to improve nozzle performance. Moderate success was obtained with Teflon-coated nozzle parts to reduce the tendency of the hot melt material to adhere to the nozzle. However, it appeared that some type of additional heating would be necessary at the nozzle exit to keep the hot melt material from solidifying. Three possible approaches are: (1) use a hot-water film co-extruded above and below the hot melt, (2) provide a steam passage at the extreme exit of the nozzle, and (3) use both methods in combination to achieve the desired results. Because these approaches required a completely new nozzle with at least seven different chambers for water, steam, and hot melt material, it was decided to defer this proposed approach temporarily and investigate another hot melt compound dispensing concept which was basically different but could use the existing nozzle.

Curtain Coat Method

The sketch in Figure 18b shows an approach for handling the production of hot melt films where the water is not in contact with the nozzle. Because the hot melt nozzle outlet does not contact the water, the hot melt compound remains molten until it strikes the water. This setup was simulated in the laboratory by mounting the nozzle vertically above the water in the test tank without the air bubble chamber. It was possible to obtain a large quantity of continuous film in this manner. An appreciable variation of thickness was noted in both the longitudinal and transverse sections of the film. However, the obvious cause of this condition was a variation in the rate at which the chilled film was removed from the surface of the water. Small bubble holes also appeared in the film which were probably a result of entrapped water vapor from leaks between the hot melt chamber and the steam jacket. Nevertheless, this experiment was the first in which a quantity of substantially whole film was made with the hot melt material.

Continuous Draw Bar Method

Consideration of the problems in this approach leads one back to the method used in bench-scale experiments to produce hot melt film samples; that is, a draw bar. The molten material is drawn down against a surface and produces uniform thin films. The apparatus in Figure 18c

shows how continuous film forming may be accomplished based on this method. Molten hot melt material is fed to a trough formed by the curve of a moving Teflon-coated drum and a draw bar. The film is chilled on the bottom side by contact with the drum and on the other side when it contacts the water. Film is stripped off the bottom of the drum.

It was decided to fabricate a bench scale model of this apparatus which would produce hot melt film about 6 inches wide. Figure 19 shows this apparatus with the draw bar positioned at about 15 degrees down from the vertical. The small plastic pan provides the cooling water and the squeeze blade mounted against the drum prevents droplets of water from prematurely chilling the hot melt material as it is poured behind the draw bar.

Continuous lengths of hot melt film of up to 100 feet long, in thickness of 0.006 to 0.014 inches have been made. Figure 20 shows film being produced on the apparatus. The length of film that can be produced appears to be limited only by the supply of hot melt material. Every experimental run with filled and unfilled hot material was successful. The only shortcoming appears to be a mild longitudinal serration which apparently is caused by a chilling of small particles adhering to the exit edge of the draw bar.

Heating of the draw bar--perhaps with an electric heater--should eliminate this problem or a heated "pressure" roll could be used following the draw bar.

Preformed Film Experiments

The films which are expected to be formed from either the hot melt compounds or from the coagulable polymers are solid, flexible, and rather strong. These physical characteristics appear to be necessary for long life and good barrier properties. When the application apparatus of these films is visualized, there is a striking similarity to an apparatus system which dispenses preformed film from a roll. The physical character of the films which have been developed so far is not unlike common preformed films which are made in large commercial quantities. Therefore, it appeared prudent to look at the problems of handling preformed film under water in the test tank so that problems with the candidate film material systems could be anticipated, and because preformed films could conceivably produce barrier properties superior to "in situ" processes at a lower cost.

The first experiments were conducted to show that preformed films can be deployed under water to cover the bottom. To accomplish this result, several conditions must be met:

- The material plus weights must have a specific gravity greater than 1.0.
- Weights must be placed in such a manner as to stabilize and keep the film down.

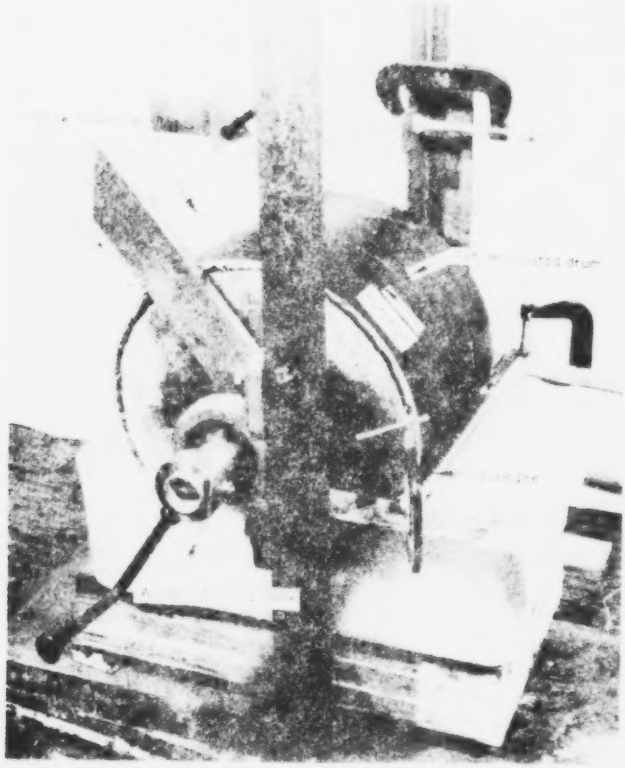


FIGURE 19. ARRANGEMENT OF CONTINUOUS DRAW-DOWN APPARATUS

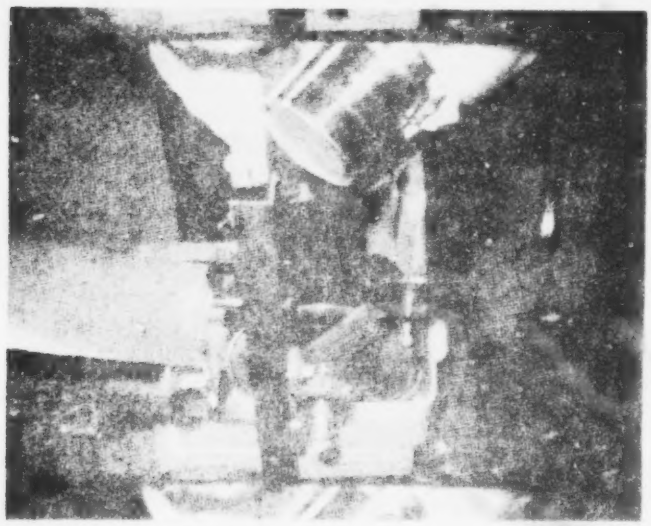


FIGURE 20. CONTINUOUS DRAW-DOWN APPARATUS IN OPERATION

- The material must have sufficient thickness or stiffness to prevent wrinkling and folding.

Good results were obtained using 0.004 low-density polyethylene with concentrated weights attached in a pattern over the film surface. We did attempt to use 0.001 Saran which has a higher specific gravity than polyethylene, but this material was too limp to be successfully laid in the tank bottom in a whole piece. A number of experiments were conducted involving the placement of weight on polyethylene film and its subsequent application to the bottom of the test tank. A summary of these experiments is shown in Table 4.

The experiments demonstrated the feasibility of fabricating a preformed film and applying it to the bottom. Another experiment was planned to demonstrate the application of preformed film. In this experiment a 10-foot-wide by 85-foot-long preformed polyethylene sheet was prepared with concentrated weights in a 2.8-foot by 2.8-foot matrix. The anchors averaged 0.021 pound per square foot. The film was rolled onto a 6-inch-diameter core and bright stripes were painted on its surface for visibility. This film was very successfully deployed to the full length of a 75-foot long indoor swimming pool. After initial deployment the film was rerolled underwater onto the core. The film was subsequently unrolled and rerolled two additional times. Figure 21 shows the film in various stages of deployment.

Based on this very successful experiment, more data on preformed film was obtained and dialysis experiments were conducted with typical commercially available materials.

ANALYSIS OF IMPLEMENTATION COSTS

The only practical means for generating an understanding of the cost of implementation of these candidate systems is to generate a possible mission profile and apply incremental cost estimates to each of the elements which have been identified as part of the system to be implemented. Obviously, since the work that has been done so far has been accomplished on a laboratory scale, and specific quotations have not been obtained, the cost estimates are credible primarily in a comparative sense. Hopefully this initial effort can serve as a worksheet which can be improved and revised as more concrete cost data are obtained. The cost analysis consists of estimates for several elements of the overall costs for the three material/equipment systems identified in this program. Thus costs have been estimated for material, predeployment operations, deployment operations and equipment for systems which utilize preformed film, a nylon/alcohol coagulable polymer, and hot melt materials.

Cost of Materials

The cost of the basic materials is based on a number of considerations

TABLE 4. SUMMARY OF PREFORMED FILM EXPERIMENTS

Film Material	Anchor	Anchor Placement	Comments
Polyethylene 2' x 10' x 0.004	Sand	Loose placed.	Polyethylene floated out from under the sand and sand ran to low spots. (tank)
Polyethylene 2' x 10' x 0.004	Sand	Glued all over.	Polyethylene stayed down but became stiff due to the rubber base glue. (tank)
Polyethylene 1' x 12' x 0.004	Sand	Glued in strips.	More flexible, stayed down but wanted to float between, rubber base glue. (tank)
Polyethylene 1' x 12' x 0.004	Sand	Glued in buttons or lumps over surface.	Stayed down and conformed rather well, epoxy bond came off after immersion. (tank)
Polyethylene 2' x 6' x 0.004	Sand	Contained in heat sealed tubes.	Somewhat stiff in transverse direction perhaps somewhat expensive. (tank)
Polyethylene 1' x 12' x 0.004	Metal Rods 1/8"	Woven across transverse direction 6" cntr's.	Very stiff in transverse direction. (tank)
Saran 1' x 20' x 0.001	None	N.A.	Conformed reasonably well but had tendency to bunch in transverse direction. (tank)
Polyethylene 2' x 10' x 0.004	Metal discs	Glued in 1' x 1' matrix 0.28 #/ft^2	Good conformation to bottom. (tank)
Polyethylene 2' x 10' x 0.004	Metal discs	Glued in 1.5' x 1.5' matrix 0.16 #/ft^2	Good conformation to bottom. (tank)
Polyethylene 4' x 8' x 0.004	Metal discs	Glued in 2.8' x 2.8' matrix 0.018 #/ft^2	Good conformation to bottom. (Placed at 12' depth in research pool)
Polyethylene 2' x 20' x 0.004	Metal discs	Glued in 1.5' x 1.5' matrix 0.16 #/ft^2	Good conformation to bottom. Used in 18' x 3' test tank and 25' x 15' x 12' research pool.
Polyethylene 10' x 85' x 0.004	Metal Discs	Taped on 2.8' x 2.8' matrix 0.018 #/ft^2	Very good results when unrolled to 75' length in swimming pool.

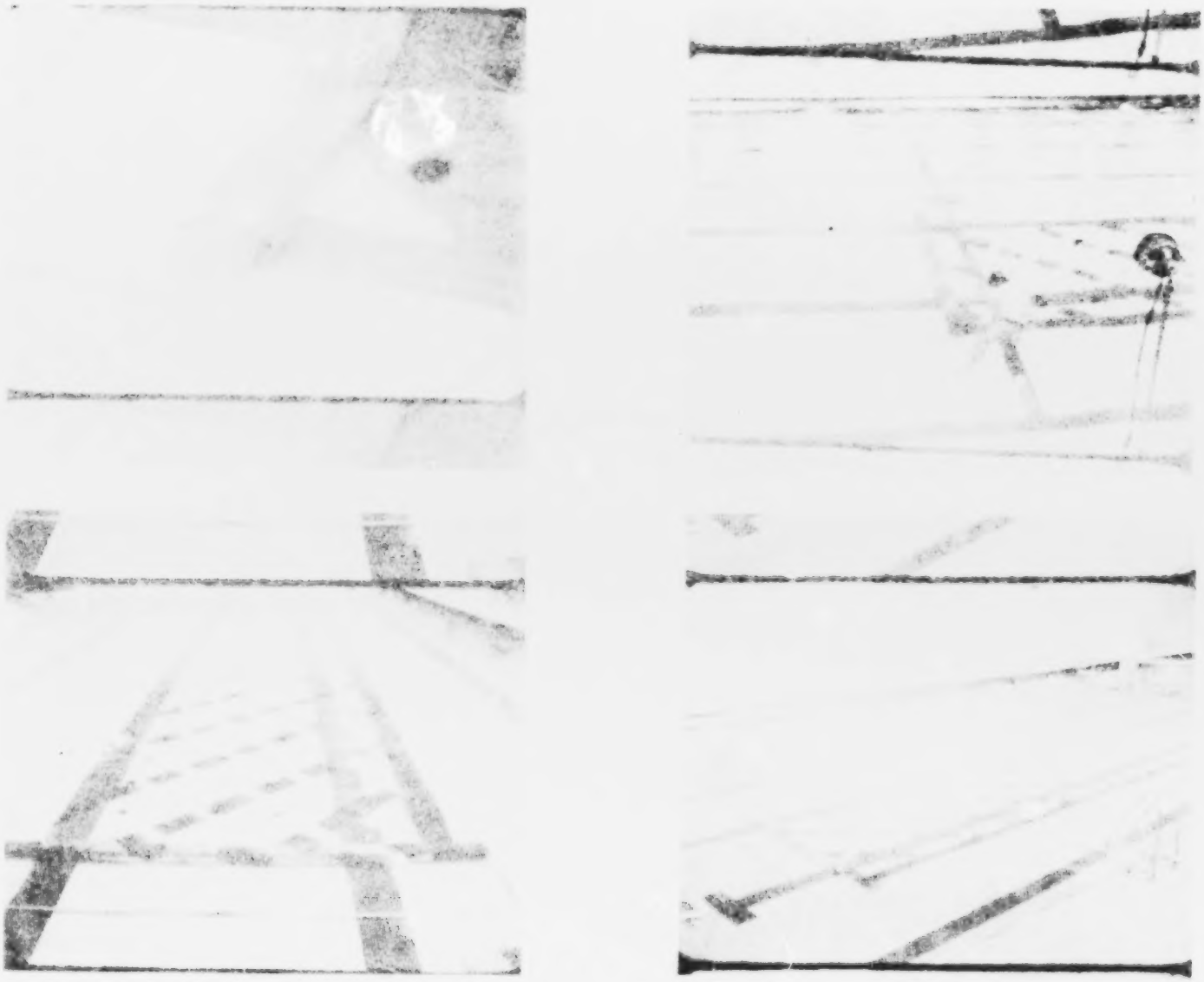


FIGURE 21. VIEWS OF LARGE-SCALE PREFORMED FILM EXPERIMENTS

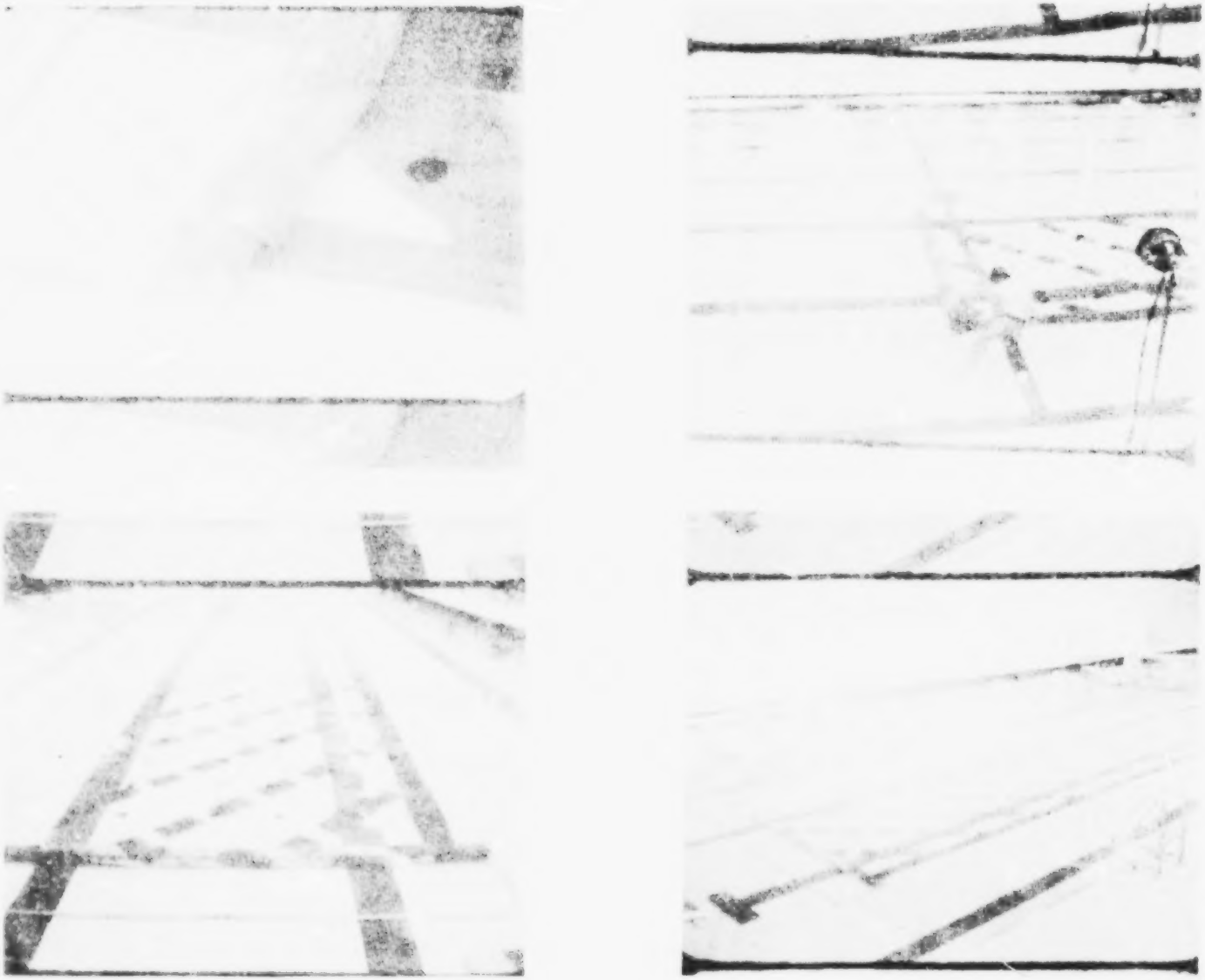


FIGURE 21. VIEWS OF LARGE-SCALE PREFORMED FILM EXPERIMENTS

including, strength, in-place thickness required, method of fabrication, and means for anchoring the film.

Basic Material Costs

The costs of materials shown in Table 5 were based on the best information available at this time. Specific gravity of some of the blends could vary, and since quotes were not obtained and the effect of quantity purchases was not determined, the cost could vary somewhat from that shown. It is believed, however, that the tables reflect a reasonable comparison of cost.

In addition to basic material and anchor weighting cost, a conversion cost is incurred with each of the candidate systems to prepare the material for deployment.

A nominal width of 20 feet has been selected as the width of overlay to be deployed. Preformed polyethylene film can be obtained in this width, but standard material is supplied in a gusset fold of only about 100 to 300 feet in length. It will be necessary, therefore, to unroll and unfold the film and reroll it on large cores 20 feet or more in length. Because more than 100 to 300-foot lengths are to be deployed, a transverse seam must also be made. Nylon, PVC, and high-density polyethylene films are available in five to seven foot widths. Therefore, continuous longitudinal seams will be necessary with these materials. It is not expected that additional labor cost will be incurred with the longitudinal seams however, and that the conversion operation could probably be accomplished at 60 feet per minute using 2 men or about $0.0003 per square foot.

Conversion costs for the nylon/alcohol and the hot melt systems involve the combination of the constituants. Nylon/alcohol will require a heated kettle with an agitator and a reflux condenser. One hundred gallon kettles are common and one man can probably handle a batch of 500 pounds which would be about 60 gallons of solution. Mixing and pumping into drums is estimated at 2 hours for a cost of $0.00250 per square foot. Hot melt materials will probably require a somewhat longer period of processing, say 2 hours, and another man will be needed to extrude, chill and pack the material after it has been melted and combined. Assuming a 500 pound batch again, the cost would be $0.0050 per square foot.

Anchoring Cost

The next cost to be considered is that of anchor materials. In previous sections of the report, three anchoring systems were described: (1) prefabricated attachment (only applied to preformed films), (2) screw-in anchors, and (3) gravel ballasting. Table 6 summarizes the estimated cost of these materials.

TABLE 5. ESTIMATED BASIC MATERIAL COST FOR POLYMER OVERLAY

Material/Equipment System	Specific Gravity	Base* Material Cost, $/pound	Deployed Film Thickness, inches	Pre-Deployment Conversion Cost, $/square foot	Total Cost, $/square foot
Preformed Nylon	1.14	1.80	.002	.0003	.0216
Preformed Polyethelene (H.D.)	0.95	0.35**	.002	.0003	.0037
Preformed Polyethelene (L.D.)	0.91	0.25	.004	.0003	.0050
Preformed PVC	1.25	0.42	.004	.0003	.0112
Alcohol-Soluble Nylon	1.05	0.40	.012	.0025	.0288
Hot Melt (EVA base)	1.05	0.24	.008	.0050	.0155
Hot Melt (EEA base)	1.05	0.19	.008	.0050	.0133

* Includes conversion cost to sheet where appropriate.

** Battelle estimate based on knowledge of process.

TABLE 6. ESTIMATED COST OF ANCHORING POLYMER OVERLAY

Anchoring Method	Material Equipment System	Cost/ pound, dollars	Weight/ square feet, pounds	Cost/ square feet, dollars
Prefabricated attachment*	All preformed films	0.090	0.018	0.00162* material 0.00139 attachment cost 0.0030
Screw-in anchors	(a) Preformed (b) Hot melt	0.090	0.018	0.0016
Ballasting	All systems	0.016	1.25	0.0020

* Although attachment of anchors in a prefabrication process could be considered with conversion costs, it has been included here to be more nearly comparative to the other "in situ" anchoring means.

Table 7 summarizes all of the predeployment costs (material, conversion, anchor).

Deployment Costs

The cost of actual deployment depends to a large extent on the specific site where the overlay will be used. Some of the factors are:

(1) Distance from land base

(2) Depth of water

(3) Weather conditions

(4) Bottom conditions

(5) Current

(6) Configuration of site.

Sample Calculations

Let us assume the following site for purposes of sample calculations:

- Site location - 50 miles from nearest land base (port)
- Site size - 20 acres (rectangular)

TABLE 7. ESTIMATED COST MATRIX, MATERIAL/PREDEPLOYMENT

Material/Equipment System	Total Basic Material Cost, $/square feet	Total Predeployment Cost, $/square feet		
		Prefabricated Anchoring, $0.0030/ square feet	Screw-in In Situ Anchoring, $0.0016/ square feet	Gravel Ballast Anchoring, $0.0020/ square feet
Preformed Nylon	0.0216	0.0246	0.0232	0.0236
Preformed Polyethelene (H.D.)	0.0037	0.0067	0.0053	0.0057
Preformed Polyethelene (L.D.)	0.0050	0.0080	0.0066	0.0070
Preformed PVC	0.0112	0.0142	0.0128	0.0132
Alcohol-Soluble Nylon	0.0288	NA	NA	0.0308
Hot Melt (EVA base)	0.0155	NA	0.0171	0.0175
Hot Melt (EEA base)	0.0133	NA	0.0149	0.0153

- Water depth - 25 feet
- Weather, bottom, and current - favorable.

Any of several equipment methods could be used, but a vessel and a barge (for barge mounted equipment) and crewmen/workmen will be required. This is estimated as follows:

Vessel 60 feet - $75/hour

Barge 80 x 40 feet - $25/hour

Crew of vessel - $20/hour/each.

Crew requirement should include 2 men for the vessel and at least 4 more men for overlay operations. A schedule of events and the resulting costs have been summarized in Table 8 for this mission.

Equipment Costs

Surface and subsurface equipment will be required to deploy the polymer film. As was shown in the sections of this report describing equipment, a barge mounted apparatus based on a commercial power crane-backhoe is being considered as the primary handling unit. This apparatus will have the subsurface polymer dispensing equipment mounted on the end of its boom.

It is estimated that the basic crane-backhoe hardware will cost $45,000 for the preformed film and hot melt approach and about $35,000 for the alcohol/nylon coagulable system based on the relative weight and bulk of the apparatus.

The cost of actual subsurface equipment for each of the candidate systems can only be a very preliminary estimate. However, the complexity of the apparatus is reflected in the comparative cost figures.

Summary cost estimates of the equipment are shown in Table 9 which follows.

TABLE 8. DEPLOYMENT COST SUMMARY

	Activity	Crew Requirement	Time, hours	Crew Cost, dollars	Vessel** Cost, dollars	Total Cost, dollars
1.	Make ready	4	8	640	200	840
2.	Start up	2	1	40	100	140
3.	To site	2	7	280	700	980
4.	On site preparation and survey	4	8	640	800	1,440
5.	Deploy film*	6	10	1,200	1,000	2,200
6.	Crew boat, etc.	4	3	240	300	540
7.	Secure equipment and evaluate overlay	6	6	720	600	1,320
8.	Return	2	7	280	700	980
9.	Secure on shore	2	1	40	100	140
10.	Secure equipment	4	8	640	200	840
	TOTAL DEPLOYMENT COST					$9,420

Sample calculations for various material/equipment concepts.

Polyethelene Preform (H.D.)	920,000 x $ .0053*** = $4,870 + $9,420 = $14,290
Nylon Preform	920,000 x $ .0232 = $21,380 + $9,420 = $30,800
Alcohol/nylon	920,000 x $ .0308 = $28,300 + $9,420 = $37,720
Hot Melt	920,000 x $ .0149 = $13,700 + $9,420 = $23,120

Thus, cost per square foot:

Polyethelene Preform (H.D.)	$14,290/920,000 = $ .0155/square foot
Nylon Preform	$30,800/920,000 = $ .0335/square foot
Alcohol/nylon	$37,720/920,000 = $ .0410/square foot
Hot Melt	$23,120/920,000 = $ .0251/square foot

* 10 rolls of .004 mill film at 100,000 to cover 46,000 x 20 acres = 920,000. square foot

** Includes workboat, barge, and crew boat as appropriate.

*** See Table 7.

TABLE 9. SUMMARY OF SURFACE AND SUBSURFACE EQUIPMENT COSTS FOR A SELECTED MISSION

Equipment Requirements	Estimated Cost, dollars
I. Preformed Film System	
1. Crane-backhoe unit	45,000
2. Subsurface equipment	
(a) Dispenser, foot roll, etc.	40,000
(b) Underwater TV, etc.	2,000
3. Surface deck equipment	
(a) Auxiliary power	3,000
(b) Deck handling	2,500
(c) Roll stands, etc.	2,500
Subtotal	95,000
II. Hot Melt Film System	
1. Crane-backhoe unit	45,000
2. Subsurface equipment	
(a) Dispenser, foot roll, etc.	75,000
(b) Underwater TV, etc.	2,000
3. Surface deck equipment	
(a) Auxiliary power	5,000
(b) Hot melt pump	5,000
(c) Deck handling, etc.	3,000
(d) Gas fired kettle	2,500
Subtotal	137,500
III. Alcohol/Nylon System	
1. Crane-backhoe unit	35,000
2. Subsurface equipment	
(a) Dispenser	30,000
(b) Underwater TV	2,000
3. Surface equipment	
(a) Auxiliary power and pumps	10,000
(b) Deck handling, etc.	2,000
(c) Vat and pumps	1,000
Subtotal	80,000

SECTION VI

IMPLEMENTATION OF RECOMMENDED APPROACH

As evidenced by the results described in the report, the concept of a polymer film barrier to contain mercury contaminants appears to be very promising. Accordingly, the next logical step is a field test to demonstrate the validity of this conclusion. A detailed description of such a demonstration program has previously been submitted to the EPA for consideration.

The program should be a carefully controlled experiment designed to evaluate the effectiveness of polymer films in reducing or eliminating the transfer of mercury into important lake biota. This work must confirm the validity of both the material performance and the concept of equipment used to deposit the film. Successful implementation of the recommended program will depend to a great degree on careful planning of the experiment followed by its execution.

Obviously, such a program will not be easy to implement, as many problems will have to be solved. Therefore, the program proposed by Battelle consists of 8 separate but related tasks planned to be executed in an efficient manner to assure a successful program. These tasks are summarized below.

Task I - Establish Program Plan - This task can be regarded as the most important part of the entire program. The success of the total effort will depend on the imagination, ingenuity, and breadth of this task, since it must shape the entire effort. The planning will determine how to treat the lake bottom (site), and how to evaluate the effectiveness of the treatment. Survey methods and experiments will be specified and analytical procedures identified. Precautions must be taken that no additional mercury is added to the site after treatment of the bottom.

Task II - Pretreatment Site Survey - Data on the levels of contamination at the site before treatment will be firmly established within the limits prescribed by the experimental plan.

Task III - Polymer Optimization - The polymer film composition will be optimized to provide the best balance of handling characteristics, barrier properties, strength, and cost.

Task IV - Equipment Design - Procedures and equipment to dispense the film, adapted to the site conditions, will be developed within the cost and time framework of the program.

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Task V - Site Treatment - The site will be treated with the polymer film.

Task VI - Post Treatment Site Survey - The site will be monitored according to the procedures and schedules established by the work plan.

Task VII - Develop Plan for Large Scale Implementation - Based on the results of Phase II, concepts and plans will be devised for large scale use of polymer films for mercury containment.

Task VIII - Technical Support Activities - The value of the demonstration can be enhanced to a considerable degree by maintaining a constant, but low rate of effort, study of polymer-mercury interactions. Of particular interest are the effect of polymer structure (crystallinity, etc.) and film orientation on mercury abosrption and permeability.

All of the above tasks are necessary to insure a successful program. Battelle-Columbus has the personnel and facilities to assume responsibility for the total management of Phase II; that is, direct participation in all 8 tasks under the supervision of an appropriate EPA project officer.

The demonstration site must be selected and some of the operating problems peculiar to the site identified before a cost proposal can be submitted.

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SECTION VII

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SECTION VIII

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TABLE A-1. RESULTS OF QUALITATIVE TESTS OF HOT MELT COMPOUNDS

Compatibility, parts by weight

Sample No.	EVA 501	Wax 3425	Wax A-143	Wax A-165	Piccotex LC	Piccotex 75	Piccolastic AL	Piccolastic A-50	Tuffin 30	PCL 700	Acrawax C	Asphalt Emulsion	Casting Temp., F	Remarks
10-2	100	-	-	-	-	-	-	-	-	-	-	-	350	Good flexibility; fair tear strength
18-1	70	30	-	-	-	-	-	-	-	-	-	-	300	Ditto
17-1	30	-	70	-	-	-	-	-	-	-	-	-	300	Ditto
11-3	30	-	-	70	-	-	-	-	-	-	-	-	250	Good flexibility; poor tear strength
17-3	70	-	-	30	-	-	-	-	-	-	-	-	250	Good flexibility; fair tear strength
17-4	33	-	-	-	-	-	-	-	25	-	-	-	300	Ditto
10-3	40	-	-	-	-	-	-	-	-	60	-	-	350	Incompatible
12-4	35	-	-	30	75	-	-	-	-	-	-	-	250	Fair flexibility; poor tear strength
13-2	24	-	-	56	20	-	-	-	-	-	-	-	250	Good flexibility; fair tear strength
11-3	25	-	-	50	25	-	-	-	-	-	-	-	320	Ditto
16-1	70	-	-	33	20	-	-	-	-	-	-	-	300	Ditto
16-1a	70	-	-	33	20	-	-	-	-	-	-	-	250	Ditto
17-3	75	-	-	-	25	-	-	-	-	-	-	-	300	Soft, rubbery film, slightly tacky
16-2	70	-	-	33	-	20	-	-	-	-	-	-	300	Good flexibility; fair tear strength
16-4	70	-	-	33	-	-	- 20	-	-	-	-	-	300	Ditto
16-3	70	-	-	33	-	-	-	20	-	-	-	-	300	Ditto
20-1	70	30	-	-	-	-	-	-	-	-	-	-	300	Ditto (blended on 3-roll mill)
17-2	70	-	15	-	-	-	-	-	-	-	15	-	350	Good flexibility; poor tear strength
24-1	50	-	-	-	-	-	-	-	-	-	-	50	300	Excellent flexibility; poor tear strength
24-2	37.5	-	25	-	-	-	-	-	-	-	-	37.5	300	Good flexibility; poor tear strength
24-3	37.5	-	25	-	-	-	-	-	-	-	-	37.5	250	Ditto

Sample No.	EVA 501	Wax A-143	Wax A-165	PCL 700	Piccotex LC	Mineral Oil	Hyrvol 90		
10-1	100	-	-	-	-	-	-	300	Good flexibility; good tear strength
18-2	70	30	-	-	-	-	-	350	Good flexibility; excellent tear strength
11-1	70	-	30	-	-	-	-	350	Good flexibility; poor tear strength
11-5	15	-	35	50	-	-	-	300	Weak, striated film
12-2	42.5	-	32.5	-	25	-	-	350	Good flexibility; good tear strength
21-4	50	50	-	-	-	-	-	260	Ditto
21-4a	50	50	-	-	-	-	-	200	Ditto
21-3	35	65	-	-	-	-	-	260	Good flexibility; fair tear strength
20-2	25	50	-	-	25	-	-	220	Good flexibility; poor tear strength
21-2	25	50	-	-	25	-	-	300	Good flexibility; poor tear strength
25-1	60	29	-	-	-	12	-	280	Good flexibility; fair tear strength
25-2	43.5	43.5	-	-	-	13	-	300	Good flexibility, poor tear strength
28-2	16	50	-	-	-	-	34	210	Good flexibility; fair tear strength
28-3	25	50	-	-	-	-	25	200	Good flexibility; fair tear strength
28-4	33.5	50	-	-	-	-	16.5	200	Good flexibility; fair tear strength

Sample No.	EVA 501	EVA 525	Wax A-143					
19-1	17.5	52.5	30					300	Good flexibility; excellent tear strength
19-2	35	35	30					300	Good flexibility; good tear strength
19-3	52.5	17.5	30					300	Good flexibility; fair tear strength
21-1	12.5	37.5	50					300	Good flexibility; fair tear strength

Sample No.	DPD-5162	Wax A-143	Wax A-165	Hyrvol 40	Hyrvol 75		
26-5	35	65	-	-	-	280	Good flexibility; fair tear strength
26-1	50	-	50	-	-	280	Good flexibility; good tear strength
26-2	35	-	65	-	-	290	Good flexibility; poor tear strength
29-1	25	50	-	25	-	280	Good flexibility; fair tear strength
29-2	50	50	-	-	-	300	Good flexibility; good tear strength
30-1	50	50	-	-	25	275	Good flexibility; poor tear strength

TABLE A-1. RESULTS OF QUALITATIVE TESTS OF HOT MELT COMPOUNDS

Sample No.	EVA 701	wax 3445	wax A-143	wax A-165	Piccotex 120	Piccotex 75	Piccolastic A5	Piccolastic A-50	Sulfio 30	PE 700	Arnowax 1	Asphalt Emulsion	Casting Temp., F	Remarks
10-2	100	-	-	-	-	-	-	-	-	-	-	-	350	Good flexibility, fair tear strength
10-1	70	30	-	-	-	-	-	-	-	-	-	-	300	Ditto
17-1	30	-	70	-	-	-	-	-	-	-	-	-	300	Ditto
15-3	30	-	-	70	-	-	-	-	-	-	-	-	250	Good flexibility, poor tear strength
17-3	70	-	-	30	-	-	-	-	-	-	-	-	250	Good flexibility, fair tear strength
17-4	33	-	-	-	-	-	-	-	25	-	-	-	300	Ditto
10-3	40	-	-	-	-	-	-	-	-	60	-	-	350	Incompatible
12-4	35	-	-	30	75	-	-	-	-	-	-	-	250	Fair flexibility, poor tear strength
13-2	24	-	-	58	20	-	-	-	-	-	-	-	250	Good flexibility, fair tear strength
13-3	23	-	-	50	23	-	-	-	-	-	-	-	320	Ditto
16-3	70	-	-	13	20	-	-	-	-	-	-	-	300	Ditto
16-1a	70	-	-	13	20	-	-	-	-	-	-	-	250	Ditto
17-1	75	-	-	-	25	-	-	-	-	-	-	-	300	Soft, rubbery film slightly tacky
15-2	70	-	-	15	-	30	-	-	-	-	-	-	300	Good flexibility, fair tear strength
15-4	70	-	-	33	-	-	20	-	-	-	-	-	300	Ditto
16-1	70	-	-	33	-	-	-	30	-	-	-	-	300	Ditto
20-1	70	30	-	-	-	-	-	-	-	-	-	-	300	Ditto (blended on 2-roll mill)
17-2	75	-	15	-	-	-	-	-	-	-	33	-	350	Good flexibility, poor tear strength
24-1	50	-	-	-	-	-	-	-	-	-	-	50	300	Excellent flexibility, poor tear strength
24-2	37.5	-	25	-	-	-	-	-	-	-	-	37.5	300	Good flexibility, poor tear strength
24-3	37.5	-	25	-	-	-	-	-	-	-	-	37.5	250	Ditto

Sample No.	EVA 701	wax A-143	wax A-165	PE 700	Piccotex 120	Mineral Oil	Elvaxol 50
10-4	100	-	-	-	-	-	-
18-2	70	30	-	-	-	-	-
11-4	70	-	30	-	-	-	-
11-1	15	-	35	50	-	-	-
12-2	22.5	-	52.5	-	25	-	-
21-4	50	50	-	-	-	-	-
21-4a	50	50	-	-	-	-	-
21-3	35	65	-	-	-	-	-
27-2	25	50	-	-	25	-	-
21-2	25	50	-	-	25	-	-
25-1	60	25	-	-	-	15	-
25-2	41.5	41.5	-	-	-	17	-
28-2	38	50	-	-	-	-	34
28-3	25	50	-	-	-	-	25
28-4	33.5	50	-	-	-	-	16.5

Sample No.	EVA 706	EVA 3.5	wax A-143
19-1	37.5	52.5	10
19-2	35	35	30
19-3	32.5	17.5	50
21-1	12.5	37.5	50

Sample No.	DPD-5152	wax A-143	wax A-165	Elvaxol 50	Elvaxol 25
26-5	35	65	-	-	-
26-1	50	-	50	-	-
26-2	35	-	65	-	-
29-1	25	50	-	25	-
29-2	50	50	-	-	-
30-1	75	50	-	-	25

Sample No.	Remarks	Casting Temp., F
26-5	Good flexibility, fair tear strength	280
26-1	Good flexibility, good tear strength	280
26-2	Good flexibility, poor tear strength	295
29-1	Good flexibility, fair tear strength	260
29-2	Good flexibility, good tear strength	300
30-1	Good flexibility, poor tear strength	275

TABLE A-2. COAGULABLE POLYMER COMPOSITIONS BASED ON UNPLASTICIZED DARAN 220 LATEX

Experiment Number	Colloid[a]	Colloid on Latex Solids, %	Total Polymer Solids, %	Coagulation Bath	Coagulation Bath Concentration, %	Remarks
33-1	---	---	61	NaOH	20	Very weak film
33-2	---	---	61	HCl	5	Very weak film; easily redispersed
33-3	---	---	61	HCl	20	Strong, brittle film; very rough surface
34-1	---	---	61	$Al_2(SO_4)_3$	20	Very brittle, crumbly film; separated into layers
34-2	---	---	61	$FeCl_3$	20	Hard, brittle, crumbly film; some separation into layers noted
5-1	Gelva C_3V_{30}	25	38	---	---	Incompatible solution
5-2	PA-6	25	38	HCl	5	Poor film, easily redispersed
5-3	PA-10	25	38	HCl	5	Ditto
5-4	Kelgin LV	3.3	31.5	HCl	5	"
6-2	PA-6	25	38	HCl	20	"
6-3	PA-10	25	38	HCl	20	"
6-4	Kelgin LV	3.3	31.5	HCl	20	Fairly weak film
7-1	Kelgin LV	3.3	31.5	$FeCl_3$	20	Ditto
18A-1	Kelcosol	1.6	31	HCl	20	"
28-1	Kelcosol	3.3	31.5	HCl	20	"
18B-1	Superloid	1.6	31	HCl	20	Somewhat stronger film; brittle
28-2	Superloid	3.3	31.5	HCl	20	Ditto
18B-2	Superloid	0.85	41	HCl	20	"
28-5	Superloid	1.6	41	HCl	20	"
18F-1	Keltex	1.6	31	HCl	20	Fairly weak film
28-3	Keltex	3.3	31.5	HCl	20	Ditto
18F-2	Keltex	0.85	41	HCl	20	"
28-6	Keltex	1.6	41	HCl	20	"
28-4	Kelgin HV	3.3	31.5	HCl	20	"
28-7	Kelgin HV	1.6	41	HCl	20	"

(a) For fuller identification see list of raw materials in Table B-1.

TABLE A-3. COAGULABLE POLYMER COMPOSITION BASED ON PLASTICIZED DARAN 220 LATEX

Experiment Number	Colloid[a]	Colloid on Latex Solids, %	Plasticizer[a]	Plasticizer on Latex Solids, %	Total Polymer Solids, %	Coagulation Bath	Coagulation Bath Concentration, %	Remarks
31-1	Superloid	0.85	Santicizer E-15	8.2	39	HCl	10	Fair emulsion stability; improved film flexibility
31-2	Superloid	0.85	Santicizer 141	8.2	39	---	---	Unstable mixture
31-3	Superloid	0.85	Santicizer B-16	8.2	39	---	---	Ditto
31-4	Superloid	0.85	Flexol TOF	8.2	39	---	---	"
36-1	---	---	Santicizer E-15	32.8	50.8	---	---	"
36-3	---	---	Santicizer E-15	19.7	54.5	---	---	"
36-2	---	---	Santicizer E-15	16.4	55.5	HCl	20	Strong, flexible film
36-4	---	---	Santicizer E-15	12.3	56.7	HCl	20	Strong film; slightly less flexible and more surface roughness than 36-2
52-1	Superloid	0.65	Santicizer E-15	16.4	47.2	$Al_2(SO_4)_3$	10	Strong film; still somewhat brittle
57-1	Superloid	0.65	Santicizer E-15	20.5	46.3	HCl	20	Strong, flexible film; high modulus of elasticity on aging
58A-1	Superloid	0.33	Santicizer E-15	20.5	51.4	HCl	20	Strong, flexible film; some surface roughness
58A-2	Superloid	0.33	Santicizer E-15	20.5	51.4	$Al_2(SO_4)_3$	20	Strong, hard film; poor flexibility
74-1	Superloid	0.65	Santicizer E-15	14.8	47.6	HCl	20	Strong, flexible film

(a) For fuller identification see list of raw materials in Table B-1.

TABLE A-4. COAGULABLE POLYMER COMPOSITIONS BASED ON FR-S 257 LATEX

Experiment Number	Colloid[a]	Colloid on Latex Solids, %	Filler[a]	Filler on Latex Solids, %	Total Polymer Solids, %	Coagulation Bath	Coagulation Bath Concentration, %	Remarks
16-3	---	---	---	---	50	HCl	20	Strong, flexible film; rough surface
34-3	---	---	---	---	50	$FeCl_3$	20	Brittle film; rough surface
34-4	---	---	---	---	50	$Al_2(SO_4)_3$	20	Brittle film; rough surface
29-1	Superloid	0.4	---	---	42	HCl	20	Strong, flexible film, rough surface
29-2	Superloid	0.8	---	---	42.4	HCl	20	Strong, flexible film
29-3	Superloid	0.8	TiO_2	10	42.4	HCl	20	Strong, flexible film
35-1	Superloid	0.4	---	---	42	HCl	10	Fairly strong, flexible film; rough surface
35-2	Superloid	0.8	---	---	42.4	HCl	10	Fairly strong, flexible film
42-3	Kelgin LV	1.0	---	---	45.8	HCl	20	Strong, flexible film
42-4	Kelgin LV	1.0	---	---	45.8	$Al_2(SO_4)_3$	20	Weak, brittle film
42-5	Kelgin LV	12	---	---	25	HCl	20	Weak, brittle film
42-6	Kelgin LV	12	---	---	25	$Al_2(SO_4)_3$	20	Fairly strong, hard film
26-1	Gelva C_3V_{30}	30	---	---	32.5	HCl	20	Fairly strong film; unstable solution
39-2	CMC R-75H	0.3	---	---	47	$Al_2(SO_4)_3$	20	Fairly weak, flexible film; some surface roughness
39-1	CMC R-75H	3	---	---	25	$Al_2(SO_4)_3$	20	Fairly weak, flexible film
40-2	CMC R-75XL	20	---	---	30	$Al_2SO_4)_3$	20	Weak, crumbly film
46-1	---	---	Sulfur	40	41.7	HCl	20	Weak, crumbly film
46-2	---	---	Sulfur	40	41.7	$Al_2(SO_4)_3$	20	Fairly strong, flexible film; rough surface
47-1	Superloid	0.8	Zinc	40	35	HCl	5	Very weak film[b]
47-2	Superloid	0.8	Zinc	40	35	$Al_2(SO_4)_3$	20	Weak, crumbly film

(a) For fuller identification see list of raw materials in Table B-1.

(b) In spite of the reduced HCl concentration and shortened contact time, the film developed numerous gas bubbles soon after immersion.

TABLE A-5. COAGULABLE POLYMER COMPOSITIONS BASED ON FR-S 194 LATEX

Experiment Number	Colloid[a]	Colloid on Latex Solids, %	Total Polymer Solids, %	Coagulation Bath	Coagulation Bath Concentration, %	Remarks
16-2	---	---	63.3	HCl	20	Very much shrinking
18C-1	Kelcosol	1.6	32.2	HCl	20	Fairly strong, flexible film
18C-2	Kelcosol	0.8	42.5	HCl	20	Slightly stronger than 18C-1
18C-3	Kelcosol	0.3	52.9	HCl	20	Slightly stronger than 18C-2
18C-4	Kelcosol	0.15	58.1	HCl	20	Slightly stronger than 18C-3; rough surface
18D-1	Superloid	1.6	32.2	HCl	20	Fairly strong, flexible film
18D-2	Superloid	0.8	42.5	HCl	20	Ditto
18D-3	Superloid	0.3	52.9	HCl	20	Fairly strong, flexible film; slight surface roughness
18D-4	Superloid	0.15	58.1	HCl	20	Fairly strong, flexible film; rough surface
18G-1	Keltex	1.6	32.2	HCl	20	Fairly strong, flexible film
18G-2	Keltex	0.8	42.5	HCl	20	Fairly strong, flexible film; slight surface roughness
18G-3	Keltex	0.3	52.9	HCl	20	Slightly stronger than 18G-2; rough surface
18G-4	Keltex	0.15	58.1	HCl	20	Slightly stronger than 18G-3; rough surface
26-3	Gelva C_3V_{30}	12	47.2	HCl	20	Fairly strong, flexible film
26-4	Gelva C_3V_{30}	50	31.1	HCl	20	Strong, hard film; much shrinkage

(a) For fuller identification see list of raw materials in Table B-1.

TABLE A-6. TABULATION OF MISCELLANEOUS LATEX EXPERIMENTS

Experiment Number	Latex[a]	Colloid[a]	Colloid on Latex Solids, %	Plasticizer[a]	Plasticizer on Latex Solids, %	Total Polymer Solids, %	Coagulation Bath Concentration, %	Coagulation Bath	Remarks
16-4	FR-S 2003	---	---	---	---	59.2	HCl	20	Very much shrinkage
26-2	FR-S 2003	Gelva C_3V_{30}	25	---	---	37.1	HCl	20	Fairly weak film; poor elasticity; about 25 % shrinkage
16-5	FR-S 2004	---	---	---	---	60.0	HCl	20	Very much shrinkage
51-2	FPC 790	---	---	---	---	50.0	HCl	20	Very rough surface
55-1	FPC 790	Superloid	0.8	---	---	42.0	HCl	20	Very weak film
55-2	FPC 790	Superloid	0.8	---	---	42.0	$Al_2(SO_4)_3$	20	Weak, crumbly film
62-1	FPC 790	---	---	Santicizer E-15	30	43.5	HCl	20	Very soft, weak film
62-2	FPC 790	Superloid	0.8	Santicizer E-15	30	29.7	HCl	20	Soft, fairly weak film
53-3	FPC 7299B	---	---	---	---	56.0[b]	HCl	20	Very rough surface
54-1	FPC 7299B	Superloid	0.8[b]	---	---	47.0[b]	HCl	20	Fairly strong, hard, flexible film
54-2	FPC 7299B	Superloid	0.8[b]	---	---	47.0[b]	$Al_2(SO_4)_3$	20	Fairly strong, hard film; poor flexibility
53-1	FPC XR7351	---	---	---	---	50.0	HCl	20	Very rough surface
56-1	FPC XR7351	Superloid	0.8	---	---	42.0	HCl	20	Fairly strong film; poor flexibility
56-2	FPC XR7351	Superloid	0.8	---	---	42.0	$Al_2(SO_4)_3$	20	Weak, brittle film
61-1	FPC XR7351	---	---	Santicizer E-15	30	43.5	HCl	20	Poor film formation
61-2	FPC XR7351	Superloid	0.8	Santicizer E-15	30	29.7	HCl	20	Weak film; poor flexibility
66-1	FPC XR7351	Superloid	0.8	Santicizer E-15	20	38.8	H_2SO_4	50	Fairly strong, flexible film; somewhat rough surface

(a) For fuller identification see list of raw materials in Table B-1.

(b) Calculated on preplasticized latex solids.

TABLE A-7. ELVAMIDE 8061 COMPOSITIONS

Experiment Number	Elvamide[a] Concentration, %	Alcohol	Water, % of total solvent	Filler	Filler on Elvamide, %
69-1	10	Ethanol	10	---	---
69-2	10	Methanol	20	---	---
69-3	25	Methanol	20	---	---
69-4	23.8	Methanol	20	TiO_2	20
71-1	10	Methanol	20	Avibest-C[b]	10
72-1	25	Ethanol	20	---	---
72-2	20.8	Ethanol	20	TiO_2	80
72-3	22.6	Ethanol	20	TiO_2	40
73-1	25	Ethanol	10	---	---

(a) Du Pont's Elvamide 8061, alcohol-soluble nylon.

(b) For further identification see list of raw materials in Table B-1.

TABLE B-1. IDENTIFICATION OF RAW MATERIALS

Trade Name	Description	Manufacturer
	Coagulable Compositions	
Latices		
Daran 220	Polyvinylidene chloride, ca. 61% solids	Grace Organic Chemicals
FR-S 259	Carboxylated, 50/50 styrene-butandiene copolymer, ca. 50% solids	Firestone Synthetic Rubber and Latex Company
FR-S 194	25/75 styrene-butadiene copolymer, ca. 62.5% solids	Ditto
FR-S 2003	29/71 styrene-butadiene copolymer, 59.2% solids	"
FR-S 2006	Polybutadiene homopolymer, ca. 60% solids	"
FPC 750	Polyvinyl chloride homopolymer, unplasticized, ca. 60% solids	Firestone Plastics Company
FPC 72998	Polyvinyl chloride copolymer, plasticized with 35 parts dioctylphthalate, ca. 56% solids	Ditto
FPC XP7351	Polyvinyl chloride-acrylic copolymer, ca. 50% solids	"
Colloids		
Kelcosol	Sodium alginate, high viscosity, refined	Kelco Company
Kelgin HV	Ditto	Ditto
Kelgin LV	Sodium alginate, low viscosity, refined	"
Keltex	Sodium alginate, high viscosity, technical	"
Superloid	Ammonium alginate, high viscosity, technical	"
CMC 8-75-H	Sodium carboxymethylcellulose, high viscosity	E.I. Du Pont de Nemours and Co.
CMC 8-75-XL	Sodium carboxymethylcellulose, extra low viscosity	Ditto
Gelva C_3V_{30}	Carboxylated polyvinyl acetate copolymer	Monsanto Company
PA-6	Hexene-1/maleic anhydride copolymer	Gulf Oil Chemical Company
PA-10	Decene-1/maleic anhydride copolymer	Ditto
Plasticizers		
Santicizer E-15	Phthalyl glycolate ester	Monsanto Company
Santicizer B-16	Ditto	Ditto
Santicizer 141	Phosphate ester	"
Flexol TOF	Tri (2-ethylhexyl) phosphate	Union Carbide Corporation
Solvent System Components		
Elvamide 8061	Polyamide terpolymer	E.I. Du Pont de Nemours and Co.
TiO_2	Anatase titanium dioxide, grade FF*	Ditto
Avibest-C	Microcrystalline silicate	FMC Corporation
	Hot Melt Blends	
Polymers		
EVA 501, 505 & 508	Ethylene vinyl acetate	Union Carbide Corporation
DPD-6169 & 9169	Ethylene ethyl acrylate	Ditto
EAA-9300 & 9500	Ethylene acrylic acid	"
PCL-700	Polycaprolactone	"
AC-580	Ethylene organic acid	Allied Chemical Company
Modifiers		
Elvaxel 30, 60 & 75	Low molecular weight polyethylene	Velsicol Chemical Corporation
Piccotex LC & 75	Vinyl toluene copolymer	Pennsylvania Industrial Chemicals
Piccolastic A5 & A-50	Ditto	Ditto
Tuffin 30	EVA/wax blend	Atlantic Refining Company
Mineral oil	Mineral oil	Pennsylvania Refining Company
Epolene C	Polyethylene wax	Eastman Chemical Company
Asphalt emulsion	Asphalt	Ashland Chemicals
Polywax 2000	Low molecular weight polyethylene	Petrolite Corp., Bareco Division
Waxes		
Aristowax A-143 & A-165	Paraffin wax	Union Oil Company
Sun 3625 & 4417	Ditto	Sun Oil Company
Acrowax E	Microcrystalline wax	Glycol Products Corporation
Fillers		
Zinc dust	Zinc	New Jersey Zinc Company
Barytes	Barium sulfate	Various
Sulfur flowers	Sulfur	Stauffer Chemical Company

TABLE B-2. TABULATION OF COMMERCIALLY AVAILABLE FILMS[a]

Listed in Decreasing Order of Density

Film Type	Specific Gravity	Thickness Range, mils	Maximum Width, inches
Vinylidene-vinyl chloride	1.59-1.71	0.4-0.6	68
Cellophane	1.40-1.50	0.75-1.7	67
Polyester (Mylar)	1.38-1.41	0.15-14	120
Vinyl Chloride-Acetate, non-plasticized	1.30-1.40	0.8-40	72
PVC, solvent cast, non-plasticized	1.30-1.40	1-4	54
Cellulose Acetate	1.28-1.31	0.5-350	60
Cellulose Triacetate	1.28-1.31	0.8-20	46
PMMA, Korad A, white	1.26	1.5-6	62[b]
Polysulfone	1.24-1.35	2-225	52
Polyvinyl Alcohol	1.21-1.31	0.5-12	54
PVC, plasticized	1.20-1.80	0.5-80	96
PVC, non-plasticized	1.20-1.50	0.6-75	84
Vinyl Chloride-acetate, plasticized	1.20-1.35	0.8-10	84
PVC, solvent cast, plasticized	1.20-1.35	1-10	54
Cellulose Propionate	1.20	3-30	48
Polycarbonate	1.20	0.25-500	54
Cellulose Acetate Butyrate	1.19-1.20	1.1-350	48
PMMA, oriented	1.18-1.19	5-10	43
PMMA, Korad C	1.17	2-6	62[b]
Ethyl Cellulose	1.15	2-15	42
Nylon 6/6	1.14	5-20	20
Nylon 6	1.13	5-30	84
Polyurethane	1.11-1.24	0.5 & up	68
Rubber Hydrochloride	1.11	0.4-2.5	60
Vinyl-nitrile rubber alloy	1.10-1.30	1-3	54
Polystyrene, oriented	1.05-1.06	0.25-20	76
ABS	1.04	10-500	105
Nylon 11	1.03	1-50	28
Nylon 12	1.01	0.5-60	--
Polyethylene - HD	.941-.965	0.4 & up	60
Ionomer	0.940	1-10	60
Polyethylene - MD	.926-.940	0.3 & up	240
Ethylene/Vinyl acetate	.924-.950	0.75 & up	480
Polyethylene - LD	.910-.925	0.3 & up	480
Polypropylene - biaxially oriented	.902-.907	0.5-1.5	72
Polypropylene - cast	.885-.895	0.87 & up	60

(a) Modern Plastics Encyclopedia, Vol. 48, No. 10A, 1971-1972. This information is not all-inclusive; for instance, Nylon 6 is known to be available in 2-mil thickness.

(b) To 108 on custom basis.

TABLE B-3. TABULATION OF FILM MANUFACTURERS[a]

Generic Film Type	Trade Name	Manufacurer[b]
Regenerated cellulose	Cellophane	(5)
	Cellophane	(16)
Cellulose acetate	Kodacel	(6)
Cellulose triacetate	Kodacel	(6)
Cellulose acetate butyrate	Kodacel	(6)
Cellulose acetate propionate	Forticel	(3)
Ethyl cellulose	Ethocel sheeting	(4)
Polyacrylonitrile	Barex	(18)
Polyamide	Capran	(1)
	Fosta	(9)
Polycarbonate	Lexan	(10)
Polyester	Celnar	(3)
	Mylar	(5)
	Kodar	(6)
Polyethylene	Polyfilm	(4)
	Visqueen	(7)
	Zendel	(20)
Polypropylene	Udel	(20)
	Pro-fax	(13)
	Kordite	(14)
Polystyrene	Trycite	(4)
	Polyflex	(15)
Polyvinyl alcohol	Reynolon	(17)
PVC, flexible	Resinite	(2)
	Velon	(8)
	Vita film	(11)
	Reynolon	(17)
PVC, rigid	Oriex	(19)
	Vynex	(19)
	Mirrex	(19)
PVDC	Saran Wrap	(4)
	Cryovac	(12)
Rubber hydrochloride	Plioflim	(11)

(a) Plastics Film Technology, W. R. R. Park, editor. Van Nostrand Reinhold Co., New York, 1969, pp. 144-145

(b) For code identification of manufacturers see Table B-4.

TABLE B-4. CODE IDENTIFICATION - FILM MANUFACTURERS

Code	Manufacturer
(1)	Allied Chemical Corp., Plastics Division, Morristown, N.J.
(2)	Borden Chemical Div., Borden, Inc. New York, N.Y.
(3)	Celanese Plastics Company, Newark, N.J.
(4)	Dow Chemical Co., Midland, Michigan
(5)	E. I. Du Pont & Co., Wilmington, Delaware
(6)	Eastman Chemical Products, Kingsport, Tenn.
(7)	Ethyl Corp, Industrial Chemicals Div., Baton Rouge, La.
(8)	Firestone Plastics Co., Pottstown, Pa.
(9)	Foster Grant Co., Leominster, Mass.
(10)	General Electric Co., Plastics Dept., Pittsfield, Mass.
(11)	Goodyear Tire & Rubber Co., Plastic Film & Sheeting Dept., Akron, O.
(12)	W. P. Grace & Co., Polymers & Chemicals Div., Cambridge, Mass.
(13)	Hercules Incorporated, Wilmington, Del.
(14)	Mobil Chemical Co., Films Dept., Masedon, N.Y.
(15)	Monsanto Company, St. Louis, Mo.
(16)	Olin Corp., Plastics Operations, Stamford, Conn.
(17)	Reynolds Metals Co., Richmond, Va.
(18)	Vistron Corp., sub. SOHIO, Cleveland, O.
(19)	Tenneco Chemicals, Inc., Tenneco Plastics Div., Piscataway, N.J.
(20)	Union Carbide Corp., Chemicals & Plastics, New York, N.Y.

APPENDIX C-1
SAMPLE CALCULATIONS OF COST OF SELECTED
HOT MELT COMPOUNDS

Material Price

Price:	$/lb
EAA-9500	0.535
EAA-9300	.70
EVA-501	.59
EVA-505	.54
DPD-6169	.315
DPD-9169	.315
Klyrvel-30	.24
Klyrvel-60	.24
Aristowax	.16
Barytes	.02

	Wt. grams:	Wt., %		Price, $		Total Cost, $
EVA 501	25	20.8	x	.54	=	.116
Klyrvel 30	25	20.8	x	.24	=	.050
Aristowax A-143	50	41.7	x	.16	=	.067
Barytes	20	16.7	x	.02	=	.003
	120	100.0				$0.236

DPD-6169 (EEA)	20.8 x .315	= .065
Klyrvel 30	20.8 x .24	= .050
Aristowax A-143	41.7 x .16	= .067
Barytes	16.7 x .02	= .003
		$0.185

APPENDIX C-2

SAMPLE CALCULATIONS OF COST OF ALCOHOL-SOLUBLE NYLON

Materials	lb.	gal.	$
EtOH (190 proof)	150	22.78	12.30
Water	37.5	4.50	---
Elvamide 8061	62.5	6.80	112.50
Barytes	62.5	1.69	1.25
	312.5	35.77	126.05

d = 1.047 = 8.736 lb/gal

Cost = $0.405/lb = $3.53/gal

= $0.0093/ft^2/dry mil

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

W

POLYMER FILM OVERLAY SYSTEM FOR MERCURY CONTAMINATED SLUDGE - PHASE I

Epstein, M. M.
Widman, M. U.

BATTELLE
Columbus Laboratories
Columbus, Ohio 43201

16080 HTZ

68-01-0088

Many polymer films concepts for sealing mercury contaminated sediments were studied, including in situ extrusion and coagulation of latices, in situ extrusion of hot melts, in situ extrusion of alcohol soluble nylon, and deployment of preformed commercial films (nylon, low and high density polyethylene, polyvinyl chloride). Materials were selected for detailed study on the basis of barrier properties to mercury compounds, strength, handleability, and estimated service life. It was found in laboratory tests that the absorption and barrier properties of polymers depend upon the type of polymer and the specific mercury compound. Most polymers are effective barriers to $HgCl_2$. However, the resistance to organic mercury compounds can vary from poor to very good. The most effective barrier to organic mercury of those studied is nylon 6, and the second most effective is high density polyethylene. Methyl mercuric chloride and dimethyl mercury were found to be very similar in their interactions with specific polymers. It was concluded that polymer films can be effectively utilized to seal mercury contaminated sediments. Equipment concepts for film deployment were demonstrated in large tank and swimming pool tests. The estimated costs for film deployment are shown in the report. Field demonstration of the nylon 6 system has been recommended.

*Water Pollution, *Sediments, *Mercury (metal), *Mercury Compounds, *Pollution Control, *Lakes, *Lake soils, *Streambeds, *Polymers, *Barriers, *Films, *Application Equipment, Plastics, Polyethylene, Nylon, Permeability, Coatings, Polyvinyl chloride, Lake sediments, Economic prediction.

*Mercury Barriers, *Mercury Absorbers, Latices, Hydrocarbon polymers, Vinyl copolymer latices, Low density polyethylene, High density polyethylene, Nylon 6, Hot melts, Polyethylene copolymers, Dimethyl mercury, Methyl-mercuric chloride, Mercuric chloride.

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